Metallaphotoredox-Catalyzed sp^3–sp^3 Cross-Coupling of Carboxylic Acids with Alkyl Halides

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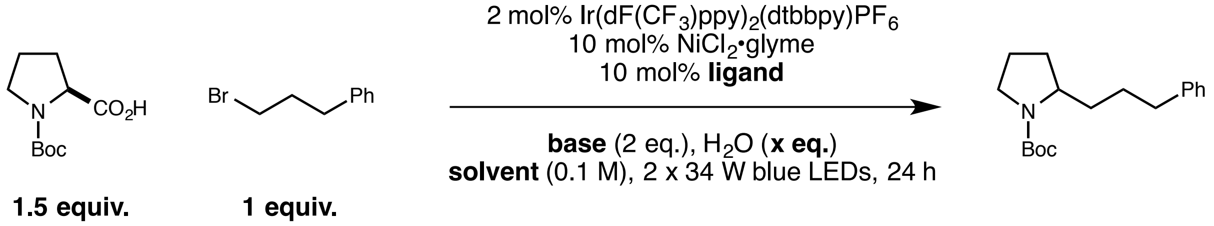
General Information

All solvents were purified according to the method of Grubbs.[1] The photocatalyst Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**), Ir[dF(Me)ppy]$_2$(dtbbpy)PF_6 (**II**) and Ir[dF(F)ppy]$_2$(dtbbpy)PF_6 (**III**) were prepared using literature procedures.[2] All of the alkyl halides and carboxylic acids, with the exception of 9-bromononanal, which was synthesized according to a literature procedure[3], were used as received. Organic solutions were concentrated under reduced pressure on a Büchi rotary evaporator using a water bath. Chromatographic purification of products was accomplished using forced-flow chromatography on silica gel (Fluka, 230–400 mesh) according to the method of Still.[4] Thin-layer chromatography (TLC) was performed on Silicycle 0.25 mm silica gel F-254 plates. Visualization of the developed chromatogram was performed by fluorescence quenching or staining with $KMnO_4$, ninhydrin, CAM, or PMA. ^{1}H NMR spectra were recorded on a Bruker UltraShield Plus Avance III 500 MHz unless otherwise noted and are internally referenced to residual protio $CDCl_3$ signals (7.26 ppm), CD_3CN (1.94 ppm) or CD_3OD (3.31 ppm). Data for ^{1}H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = quintet, m = multiplet, dd = doublet of doublets, dt = doublet of triplets…etc, br = broad), coupling constant (Hz) and integration. ^{13}C NMR spectra were recorded on a Bruker UltraShield Plus Avance III 500 MHz (125 MHz) and data are reported in terms of chemical shift relative to $CDCl_3$ (77.16 ppm) or CD_3CN (1.32 ppm). IR spectra were recorded on a Perkin Elmer Spectrum 100 FTIR spectrometer and are reported in wavenumbers (cm^{-1}). High Resolution Mass Spectra were obtained from the Princeton University Mass Spectral Facility.

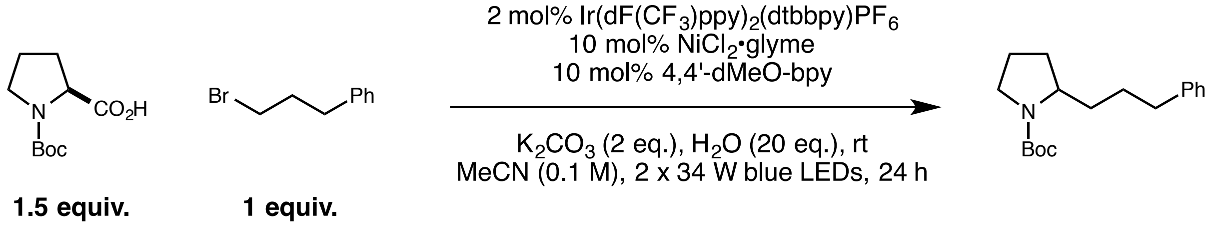
Optimization Table



Solvent	Base	Ligand	H_2O	Product	PhProp-Br	Ester
DMF	Cs_2CO_3	dtbbpy	none	**0%**	0%	100%
DME	Cs_2CO_3	dtbbpy	none	**9%**	68%	27%
dioxane	Cs_2CO_3	dtbbpy	none	**10%**	81%	13%
EtOAc	Cs_2CO_3	dtbbpy	none	**9%**	80%	11%
Acetone	Cs_2CO_3	dtbbpy	none	**11%**	22%	69%
MeCN	Cs_2CO_3	dtbbpy	none	**49%**	0%	38%
MeCN	K_2CO_3	dtbbpy	none	**68%**	0%	11%
MeCN	K_2CO_3	dMeO-bpy	none	**74%**	0%	14%
MeCN	K_2CO_3	dMeO-bpy	10 eq.	**91%**	0%	2%
MeCN	K_2CO_3	dMeO-bpy	20 eq.	**92%**	0%	2%
MeCN (48 h)	K_2CO_3	dMeO-bpy	20 eq.	**96%**	0%	2%

Figure S1. Optimization of the reaction conditions for the decarboxylative cross-coupling of carboxylic acids and alkyl halides. Yields determined by GC analysis using hexadecane as an internal standard. Reactions were performed on a 0.100 mmol scale.

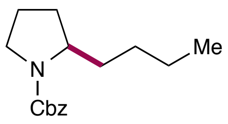
Control Reactions



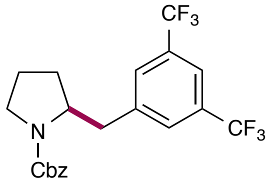
Control	**Product**
No nickel	**0%**
No ligand	**0%**
No photocat.	**0%**
No light	**0%**
No base	**0%**
No degas	**26%**

Figure S2. Control reactions for the decarboxylative cross-coupling of carboxylic acids and alkyl halides. Yields determined by GC analysis using hexadecane as an internal standard. Reactions were performed on a 0.100 mmol scale.

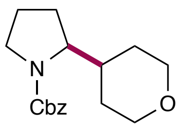
Additional Examples



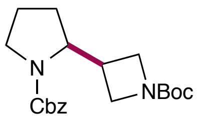
(±)-46 76% yield



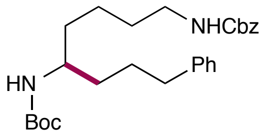
(±)-47 59% yield



(±)-48 83% yield

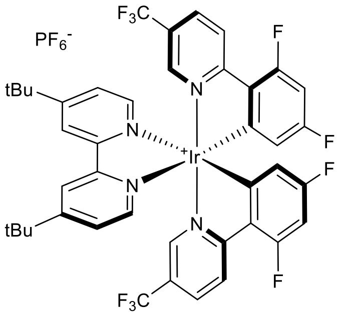


(±)-49 50% yield

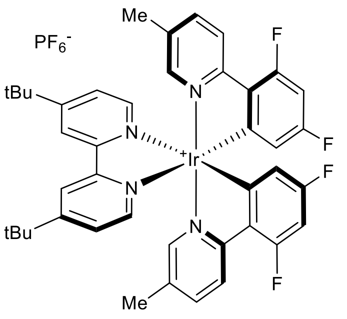


(±)-50 65% yield

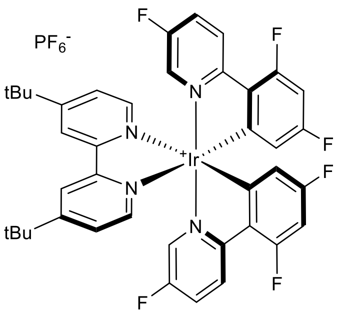
Figure S3. Additional examples of decarboxylative cross-coupling of carboxylic acids with alkyl halides. Isolated yields are reported. Reactions for **45 - 47** were performed following general procedure A, **48** was synthesized following general procedure B.



Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$
I



Ir[dF(Me)ppy]$_2$(dtbbpy)PF$_6$
II



Ir[dF(F)ppy]$_2$(dtbbpy)PF$_6$
III

Figure S4. Used Ir-Photocatalysts.

Experimental Data

General Procedure A for Decarboxylative Alkylation (Alkyl Halide Scope):

An oven dried[*] 8 mL vial equipped with a Teflon septum and magnetic stir bar was charged with Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (10.0 µmol, 0.02 equiv), $NiCl_2$•glyme (0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (0.05 mmol, 0.1 equiv), Boc-Pro-OH (0.75 mmol, 1.5 equiv), K_2CO_3 (1.00 mmol, 2.0 equiv), and 5 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (10.0 mmol, 20 equiv) and the appropriate alkyl halide (0.50 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 48 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. Purification of the crude product by flash chromatography on silica gel using the indicated solvent system afforded the desired product.

General Procedure B for Decarboxylative Alkylation (Acyclic Amino Acids):

An oven dried[*] 40 mL vial equipped with a Teflon septum and magnetic cross stir bar was charged with Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (10.0 µmol, 0.02 equiv), $NiCl_2$•glyme (0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (0.05 mmol, 0.1 equiv), the appropriate acid (0.75 mmol, 1.5 equiv), Cs_2CO_3 (1.00 mmol, 2.0 equiv), and 10 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (10 mmol, 20 equiv) and 1-bromo-3-phenylpropane (0.50 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. Purification of the crude product by preparative SFC afforded the desired product.

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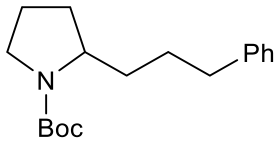
[*] Although water is an essential additive for this reaction, the vials were stored in the oven to eliminate unwanted variations of the reaction conditions and assure reproducibility throughout the entire process.

***tert*-Butyl 2-(3-phenylpropyl)pyrrolidine-1-carboxylate (12)**



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.6 mg, 10.3 µmol, 0.02 equiv), NiCl$_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (11.2 mg, 0.05 mmol, 0.1 equiv), 1-bromo-3-phenylpropane (80 µL, 0.52 mmol, 1.0 equiv), Boc-Pro-OH (167 mg, 0.77 mmol, 1.5 equiv), K$_2$CO$_3$ (143 mg, 1.03 mmol, 2 equiv), water (186 µL, 10.3 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (0 to 2% EtOAc/hexanes) as a colorless oil (127 mg, 85%).

^{1}H-NMR (500 MHz, CDCl$_3$) rotameric mixture: δ 7.31 – 7.23 (m, 2H), 7.21 – 7.14 (m, 3H), 3.81 and 3.70 (2 br s, 1H, rotamer), 3.38 and 3.29 (2 br s, 2H, rotamer), 2.61 (br s, 2H), 1.98 – 1.53 (m, 7H), 1.51 – 1.28 (m, 10H).

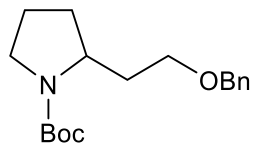
^{13}C-NMR (126 MHz, CDCl$_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 154.8, (142.8), 142.5, 128.5, 128.4, 125.8, 79.0, 57.3, (46.6), 46.2, 36.1, 34.5 (34.1), 30.8 (30.0), 28.7, 28.2, (23.9), 23.2.

IR (film): ν_{max} 2971, 2930, 1691, 1497, 1478, 1454, 1393, 1364, 1249, 1170, 1103, 914, 877, 772, 748, 699.

HRMS (ESI-TOF): m/z calcd. for $C_{18}H_{27}NNaO_2$ ([M+Na]$^+$) 312.19340, found 312.19361.

Data are consistent with those reported in the literature.[5]

tert-Butyl 2-(2-(benzyloxy)ethyl)pyrrolidine-1-carboxylate (13)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), $NiCl_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), benzyl 2-bromoethyl ether (79 µL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K_2CO_3 (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (5 to 20% EtOAc/hexanes) as a colorless oil (99 mg, 65%).

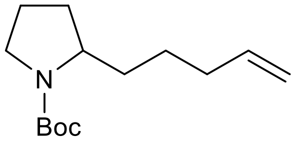
^{1}H-NMR (500 MHz, $CDCl_3$) rotameric mixture: δ 7.37 – 7.30 (m, 4H), 7.30 – 7.25 (m, 1H), 4.52 (d, *J* = 11.9 Hz, 1H), 4.47 (d, *J* = 11.9 Hz, 1H), 3.89 and 3.84 (2 br s, 1H, rotamer), 3.52 (br s, 2H), 3.38 and 3.30 (2 br s, 1H, rotamer), 2.10 and 2.05 (2 br s, 1H, rotamer), 1.98 – 1.72 (m, 4H), 1.68 – 1.57 (m, 1H), 1.45 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 154.7, 138.7, 131.0, 128.5, 127.6, 79.3 (79.0), 73.0, (68.5) 68.3, (55.5) 55.3, (46.5) 46.1, 34.9 (34.4), 31.3 (30.7), 28.7, (23.9) 23.2.

IR (film): ν_{max} 2969, 2871, 1689, 1478, 1454, 1390, 1364, 1251, 1166, 1100, 1028, 911, 865, 772, 732, 697.

HRMS (ESI-TOF): m/z calcd. for $C_{18}H_{28}NO_3$ ([M+H]$^+$) 306.20637, found 306.20664.

***tert*-Butyl 2-(pent-4-en-1-yl)pyrrolidine-1-carboxylate (14)**



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (12.3 mg, 11.0 µmol 0.02 equiv), $NiCl_2$•glyme (12.1 mg, 0.06 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (11.9 mg, 0.06 mmol, 0.1 equiv), 5-bromopentene (65 µL, 0.55 mmol, 1.0 equiv), Boc-Pro-OH (177 mg, 0.82 mmol, 1.5 equiv), K_2CO_3 (152 mg, 1.1 mmol, 2.0 equiv), water (198 µL, 11 mmol, 20 equiv), and 5.5 mL of MeCN were used. The product was isolated by flash chromatography (5 to 7.5% EtOAc/hexanes) as a colorless oil (110 mg, 84%).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.80 (ddt, *J* = 17.0, 10.2, 6.6 Hz, 1H), 5.00 (dq, *J* = 17.1, 1.7 Hz, 1H), 4.94 (dd, *J* = 10.2, 1.1 Hz, 1H), 3.78 – 3.69 (m, 1H), 3.40 – 3.26 (m, 2H), 2.13 – 1.99 (m, 2H), 1.96 – 1.68 (m, 4H), 1.67 – 1.60 (m, 1H), 1.46 (s, 9H), 1.41 – 1.25 (m, 3H).

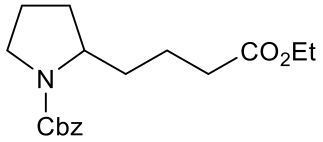
^{13}C-NMR (126 MHz, $CDCl_3$): δ 154.8, 139.0, 114.6, 79.0, 57.4, 46.4, 34.1, 33.9, 30.5, 28.7, 25.8, 23.6.

IR (film): ν_{max} 2972, 2931, 2874, 1692, 1641, 1479, 1455, 1392, 1365, 1251, 1172, 1107, 992, 911, 878, 772.

HRMS (ESI-TOF): m/z calcd. for $C_{14}H_{25}NNaO_2$ ([M+Na]$^+$) 262.17775, found 262.17793.

Data are consistent with those reported in the literature.[6]

Benzyl 2-(4-ethoxy-4-oxobutyl)pyrrolidine-1-carboxylate (15)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.0 mg, 9.8 μmol 0.02 equiv), NiCl$_2$•glyme (10.8 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.6 mg, 0.05 mmol, 0.1 equiv), ethyl 4-bromobutyrate (70 μL, 0.49 mmol, 1.0 equiv), Cbz-Pro-OH (183 mg, 0.73 mmol, 1.5 equiv), K$_2$CO$_3$ (135 mg, 0.98 mmol, 2.0 equiv), water (176 μL, 9.7 mmol, 20 equiv), and 4.9 mL of MeCN were used. The product was isolated by flash chromatography (15% Et2O/pentane) as a colorless oil (100 mg, 64%).

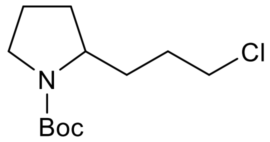
^{1}H-NMR (500 MHz, CDCl$_3$) rotameric mixture: δ 7.46 – 7.30 (m, 5H), 5.24 – 5.05 (m 2H, rotamer), 4.23 – 4.05 (m, 2H, rotamer), 3.84 (m, 1H, rotamer), 3.55 – 3.31 (m, 2H), 2.29 (m, 2H, rotamer), 1.99 – 1.77 (m, 4H), 1.73 – 1.60 (m, 3H), 1.40 – 1.31 (m, 1H), 1.28 – 1.21 (m, 3H).

^{13}C-NMR (126 MHz, CDCl$_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 173.8 (173.6), (155.2) 155.0, 137.2 (137.1), 128.6, 128.0, 127.9, 66.8 (66.6), 60.4, 57.8 (57.1), (46.7) 46.4, 34.3 (close rotamers), 33.5, (30.7) 30.0, 24.0 (23.2), 21.8, 14.4

IR (film): ν_{max} 2957, 1732, 1698, 1498, 1452, 1410, 1357, 1336, 1251, 1181, 1100, 1030, 917, 868, 769, 746, 698.

HRMS (ESI-TOF): m/z calcd. for $C_{18}H_{25}NNaO_4$ ([M+Na]$^+$) 319.17836, found 319.17772.

tert-Butyl 2-(3-chloropropyl)pyrrolidine-1-carboxylate (16)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.3 mg, 10.1 µmol 0.02 equiv), NiCl$_2$•glyme (11.1 mg, 0.051 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.9 mg, 0.05 mmol, 0.1 equiv), 1-bromo-3-chloropropane (50 µL, 0.51 mmol, 1.0 equiv), Boc-Pro-OH (163 mg, 0.76 mmol, 1.5 equiv), K$_2$CO$_3$ (140 mg, 1.0 mmol, 2.0 equiv), water (182 µL, 10.1 mmol, 20 equiv), and 5.1 mL of MeCN were used. The product was isolated by flash chromatography (7% EtOAc/hexanes) as a colorless oil (123 mg, 96%).

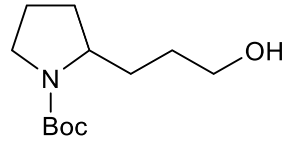
^{1}H-NMR (500 MHz, CDCl$_3$): δ 3.79 – 3.71 (m, 1H), 3.58 – 3.46 (m, 2H), 3.40 – 3.31 (m, 1H), 3.31 – 3.23 (m, 1H), 1.97 – 1.85 (m, 1H), 1.88 – 1.69 (m, 5H), 1.66 – 1.56 (m, 1H), 1.44 (s, 10H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 154.8, 79.3, 56.8, 46.4, 45.2, 32.1, 30.6, 29.8, 28.7, 23.5.

IR (film): ν_{max} 2696, 2874, 1869, 1478, 1454, 1391, 1364, 1251, 1168, 1116, 1100, 913, 875, 772, 725.

HRMS (ESI-TOF): m/z calcd. for $C_{12}H_{22}ClNNaO_2$ ([M+Na]$^+$) 270.12313, found 270.12348.

tert-Butyl 2-(3-hydroxypropyl)pyrrolidine-1-carboxylate (17)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 3-bromopropan-1-ol (45 µL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K$_2$CO$_3$ (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (17 to 25% EtOAc/hexanes) as a yellow oil (99 mg, 86%).

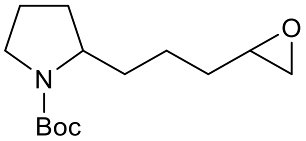
^{1}H-NMR (500 MHz, CDCl$_3$): δ 3.87 – 3.78 (m, 1H), 3.73 – 3.63 (m, 2H), 3.40 – 3.26 (m, 2H), 1.99 – 1.73 (m, 4H), 1.67 – 1.48 (m, 3H), 1.46 (s, 9H), 1.45 – 1.32 (m, 1H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 155.0, 79.3, 62.8, 56.9, 46.4, 31.0, 30.6, 29.3, 28.7, 23.6.

IR (film): ν_{max} 3428, 2971, 2872, 1780, 1692, 1672, 1478, 1457, 1397, 1366, 1251, 1169, 1109, 1059, 920, 862, 772.

HRMS (ESI-TOF): m/z calcd. for $C_{12}H_{23}NNaO_3$ ([M+Na]$^+$) 252.15701, found 252.15713. Data are consistent with those reported in the literature.[7]

tert-Butyl 2-(3-(oxiran-2-yl)propyl)pyrrolidine-1-carboxylate (18)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), $NiCl_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 2-(3-bromopropyl)oxirane (83.0 mg, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K_2CO_3 (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (10 to 15% EtOAc/hexanes) as a colorless oil and as a 1 : 1 mixture of diastereomers (106 mg, 83%).

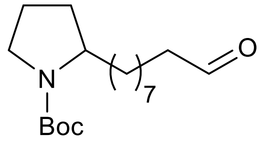
^{1}H-NMR (500 MHz, $CDCl_3$) rotameric mixture: δ 3.78 and 3.71 (2 br s, 1H, rotamer), 3.40 and 3.30 (2 br s, 2H, rotamer), 2.98 – 2.85 (m, 1H), 2.75 (t, *J* = 4.5 Hz, 1H), 2.52 – 2.41 (m, 1H), 1.97 – 1.69 (m, 4H), 1.69 – 1.61 (m, 1H), 1.60 – 1.54 (m, 1H), 1.53 – 1.31 (m, 14H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 154.8, 79.1 (79.0), (57.4) 57.2, (52.5) 52.3, 47.2, (46.6) 46.2, (34.7) 34.6, 34.2 (33.9), (32.8) 32.7, 32.6 (32.5), 30.8 (30.0), 28.7 (28.6), (23.9) 23.2, (22.9) 22.8.

IR (film): ν_{max} 2971, 2931, 2871, 1689, 1479, 1455, 1391, 1365, 1253, 1168, 1107, 913, 849, 772.

HRMS (ESI-TOF): m/z calcd. for $C_{14}H_{25}NNaO_3$ ($[M+Na]^+$) 278.17266, found 278.17287.

tert-Butyl 2-(9-oxononyl)pyrrolidine-1-carboxylate (19)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 9-bromononanal (111 mg, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K$_2$CO$_3$ (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (7.5% EtOAc/hexanes) as a colorless oil (97 mg, 62%).

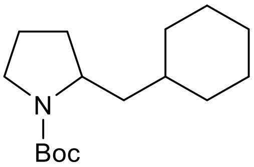
^{1}H-NMR (500 MHz, CDCl$_3$): δ 9.76 (t, J = 1.9 Hz, 1H), 3.75 – 3.67 (m, 1H), 3.39 – 3.26 (m, 2H), 2.42 (td, J = 7.4, 1.9 Hz, 2H), 1.94 – 1.67 (m, 3H), 1.67 – 1.57 (m, 4H), 1.46 (s, 9H), 1.35 – 1.20 (m, 10H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 203.1, 154.8, 79.0, 57.4, 46.4, 44.1, 34.5, 30.4, 29.7, 29.6, 29.4, 29.3, 28.7, 26.5, 23.6, 22.2.

IR (film): ν_{max} 2928, 2856, 1726, 1691, 1456, 1393, 1365, 1253, 1171, 1106, 913, 772.

HRMS (ESI-TOF): m/z calcd. for $C_{18}H_{33}NNaO_3$ ([M+Na]$^+$) 334.23527, found 334.23557.

tert-Butyl 2-(cyclohexylmethyl)pyrrolidine-1-carboxylate (20)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.2 mg, 10.0 μmol 0.02 equiv), $NiCl_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), (bromomethyl)cyclohexane (69 μL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K_2CO_3 (138 mg, 1.00 mmol, 2.0 equiv), water (180 μL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (5 to 7.5% EtOAc/hexanes) as a colorless oil (100 mg, 75%).

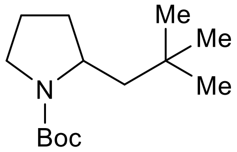
^{1}H-NMR (500 MHz, $CDCl_3$): δ 3.87 – 3.80 (m, 1H), 3.38 – 3.25 (m, 2H), 1.94 – 1.73 (m, 4H), 1.72 – 1.53 (m, 6H), 1.46 (s, 9H), 1.29 – 1.07 (m, 5H), 1.00 – 0.86 (m, 2H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 154.7, 79.0, 55.2, 46.1, 42.3, 35.5, 34.6, 32.8, 30.7, 28.7, 26.7, 26.6, 26.4, 23.3.

IR (film): ν_{max} 2971, 2922, 1851, 1692, 1478, 1449, 1391, 1364, 1254, 1171, 1105, 914, 878, 772.

HRMS (ESI-TOF): m/z calcd. for $C_{16}H_{29}NNaO_2$ ($[M+Na]^+$) 290.20905, found 290.20948.

tert-Butyl 2-neopentylpyrrolidine-1-carboxylate (21)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 1-bromo-2,2-dimethylpropane (63 µL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K$_2$CO$_3$ (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (4% EtOAc/hexanes) as a pale yellow oil (63 mg, 52%).

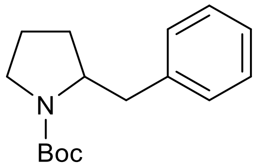
^{1}H-NMR (500 MHz, CDCl$_3$): δ 3.87 – 3.78 (m, 1H), 3.36 – 3.23 (m, 2H), 2.00 – 1.73 (m, 3H), 1.72 – 1.65 (m, 1H), 1.65 – 1.57 (m, 1H), 1.46 (s, 9H), 1.21 (dd, J = 13.5, 10.2 Hz, 1H), 0.94 (s, 9H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 154.5, 79.2, 54.6, 48.6, 45.9, 32.9, 30.4, 30.4, 28.9, 23.4.

IR (film): ν_{max} 2956, 2871, 1691, 1455, 1477, 1389, 1364, 1345, 1308, 1294, 1248, 1169, 1114, 1096, 1063, 994, 967, 923, 878, 771.

HRMS (ESI-TOF): m/z calcd. for $C_{14}H_{27}NNaO_2$ ([M+Na]$^+$) 264.19340, found 264.19302.

tert-Butyl 2-benzylpyrrolidine-1-carboxylate (22)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.2 mg, 10.0 μmol 0.02 equiv), $NiCl_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), benzyl chloride (58 μL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K_2CO_3 (138 mg, 1.00 mmol, 2.0 equiv), water (180 μL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (5 to 7.5% EtOAc/hexanes) as a colorless oil (109 mg, 84%).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.21 (t, *J* = 7.4 Hz, 2H), 7.16 – 7.10 (m, 3H), 3.91 (br s, 1H), 3.26 (br s, 2H), 3.03 (d, *J* = 12.9 Hz, 1H), 2.47 (dd, *J* = 13.0, 9.5 Hz, 1H), 1.75 – 1.59 (m, 4H), 1.44 (s, 9H).

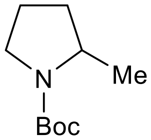
^{13}C-NMR (126 MHz, $CDCl_3$): δ 154.7, 139.4, 129.6, 128.5, 126.3, 79.3, 58.9, 46.6, 40.4, 29.5, 28.8, 23.1.

IR (film): ν_{max} 3027, 2973, 1876, 1690, 1604, 1497, 1479, 1454, 1292, 1365, 1343, 1276, 1256, 1170, 1115, 1096, 1030, 967, 902, 867, 765, 748, 701.

HRMS (ESI-TOF): m/z calcd. for $C_{16}H_{23}NNaO_2$ ([M+Na]$^+$) 284.16210, found 284.16220.

Data are consistent with those reported in the literature.[8]

tert-Butyl 2-methylpyrrolidine-1-carboxylate (23)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (13.5 mg, 12.0 μmol 0.02 equiv), $NiCl_2$•glyme (13.2 mg, 0.06 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (13 mg, 0.06 mmol, 0.1 equiv), bromomethane (3.6 M in MeCN, 166 μL, 0.6 mmol, 1.0 equiv), Boc-Pro-OH (129.0 mg, 0.6 mmol, 1.0 equiv), K_2CO_3 (166 mg, 1.2 mmol, 2.0 equiv), water (216 μL, 12 mmol, 20 equiv), and 6 mL of MeCN were used. However, to limit esterification, the reaction was run for 24 hours at 7 ºC in an isopropanol bath maintained via a portable cryo-cool. The product was isolated by flash chromatography (10% Et2O/pentane) as a colorless oil (69 mg, 62%).

Procedure for Flow reaction:

Using Vapourtec E-series equipped with a 10 ml UV-150 Photochemical reactor (420 nm), a solution of Boc-Pro-OH (107.6 mg, 0.5 mmol, 1.0 equiv.), Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.3 mg, 0.01 μmol 0.02 equiv), $NiCl_2$•glyme (2.14 mg, 0.01 mmol, 0.02 equiv), 4,4′-di-*tert*-butyl-2,2′-bipyridyl (2.71 mg, 0.01 mmol, 0.02 equiv), 1,1,3,3-tetramethylguanidine (63.0 μl, 0.50 mmol, 1.0 equiv.) and water (45.0 μl, 2.50 mmol, 5.0 equiv.) in MeCN (1 ml) and a separate solution of bromomethane (0.79 M in MeCN, 1.0 ml, 0.79 mmol, 1.58 equiv.) were pumped through the system, mixing just before entering the photoreactor with a flow rate of 0.333 ml/ min each. The yield was determined by GC vs MeOBz as internal standard (55%). Under these conditions, one could produce 22 grams (120 mmol) in 24 hours.

^{1}H-NMR (500 MHz, CDCl$_3$): δ 3.90 – 3.81 (m, 1H), 3.39 – 3.28 (m, 2H), 1.97 (ddt, *J* = 12.0, 9.5, 7.4 Hz, 1H), 1.92 – 1.72 (m, 2H), 1.58 – 1.48 (m, 1H), 1.45 (s, 9H), 1.14 (d, *J* = 6.3 Hz, 3H).

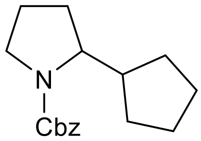
^{13}C-NMR (126 MHz, CDCl$_3$): δ 154.7, 78.9, 52.9, 46.4, 33.1, 28.7, 23.4, 20.7.

IR (film): ν_{max} 2969, 2875, 1693, 1479, 1456, 1391, 1366, 1287, 1250, 1172, 1138, 1110, 1084, 1029, 1003, 972, 902, 856, 773.

HRMS (ESI-TOF): m/z calcd. for $C_{10}H_{19}NNaO_2$ ($[M+Na]^+$) 208.13080, found 208.13105.

Data are consistent with those reported in the literature.[9]

Benzyl 2-cyclopentylpyrrolidine-1-carboxylate (24)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (9.9 mg, 8.8 µmol 0.02 equiv), $NiCl_2$•glyme (9.7 mg, 0.04 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (9.6 mg, 0.04 mmol, 0.1 equiv), bromocyclopentane (48 µL, 0.44 mmol, 1.0 equiv), Cbz-Pro-OH (165 mg, 0.66 mmol, 1.5 equiv), K_2CO_3 (122 mg, 0.88 mmol, 2.0 equiv), water (159 µL, 8.80 mmol, 20 equiv), and 4.4 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (88 mg, 72%).

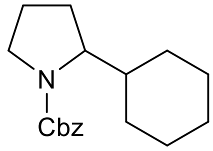
^{1}H-NMR (500 MHz, $CDCl_3$) rotameric mixture: δ 7.40 – 7.27 (m, 5H), 5.18 – 5.07 (m, 2H), 3.95 and 3.89 (2 br s, 1H, rotamer), 3.61 – 3.55 (m, 1H), 3.54 – 3.46 (m, 1H), 3.39 – 3.29 (m, 1H), 2.19 – 1.99 (m, 1H), 1.95 – 1.78 (m, 3H), 1.78 – 1.35 (m, 8H), 1.34 – 1.10 (m, 1H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 155.6, 137.4 (137.1), 128.5, 128.1, 127.9 (127.9), (66.9) 66.6, 61.5 (60.9), (46.7) 46.5, 44.2, 30.1 (28.9), (29.3) 28.5, 25.4 (25.2), 24.0, (23.1).

IR (film): ν_{max} 3033, 2950, 2869, 1696, 1587, 1498, 1451, 1406, 1355, 1330, 1284, 1205, 1185, 1151, 1098, 1029, 981, 915, 867, 768, 749, 697.

HRMS (ESI-TOF): m/z calcd. for $C_{17}H_{23}NNaO_2$ ($[M+Na]^+$) 296.16210, found 296.16183.

Benzyl 2-cyclohexylpyrrolidine-1-carboxylate (25)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (10.9 mg, 9.7 μmol 0.02 equiv), $NiCl_2$•glyme (10.7 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.5 mg, 0.05 mmol, 0.1 equiv), bromocyclohexane (60 μL, 0.49 mmol, 1.0 equiv), Cbz-Pro-OH (182 mg, 0.73 mmol, 1.5 equiv), K_2CO_3 (135 mg, 0.97 mmol, 2.0 equiv), water (176 μL, 9.70 mmol, 20 equiv), and 4.9 mL of MeCN were used. The product was isolated by flash chromatography (3 to 30% EtOAc/hexanes) as a colorless oil (80 mg, 57%).

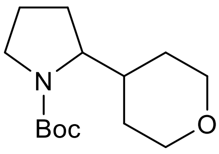
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.41 – 7.27 (m, 5H), 5.26 – 5.03 (m, 2H), 3.82 – 3.70 (m, 1H), 3.64 – 3.45 (m, 1H), 3.34 – 3.24 (m, 1H), 1.90 – 1.49 (m, 10H), 1.30 – 0.83 (m, 5H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ (155.6) 155.4, 137.4 (137.2), 128.5, 127.9, 127.9, (66.7) 66.6, 62.7 (62.0), (47.2) 46.9, (41.4) 40.7, 30.2, 27.9, 27.4, 26.7 - 26.3 (m), 24.5 (23.8).

IR (film): ν_{max} 2925, 2852, 1699, 1498, 1449, 1408, 1354, 1332, 1182, 1101, 1028, 976, 920, 880, 768, 750, 697.

HRMS (ESI-TOF): m/z calcd. for $C_{18}H_{25}NNaO_2$ ($[M+Na]^+$) 310.17775, found 310.17726.

tert-Butyl 2-(tetrahydro-2H-pyran-4-yl)pyrrolidine-1-carboxylate (26)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 4-bromotetrahydro-2H-pyran (57 µL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K$_2$CO$_3$ (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (10 to 15% EtOAc/hexanes) as a pale yellow oil (116 mg, 91%).

^{1}H-NMR (500 MHz, CDCl$_3$): δ 4.02 – 3.96 (m, 2H), 3.72 (br s, 1H), 3.52 - 3.41 (m, 1H), 3.33 (tdd, *J* = 11.6, 3.7, 2.3 Hz, 2H), 3.26 – 3.17 (m, 1H), 1.92 (br s, 1H), 1.87 – 1.72 (m, 4H), 1.53 – 1.28 (m, 13H).

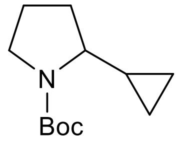
^{13}C-NMR (126 MHz, CDCl$_3$): δ 155.3, 79.3, 68.4, 68.2, 61.3, 46.9, 38.7, 30.2, 28.7, 28.3, 27.1, 24.1.

IR (film): ν_{max} 2957, 2843, 1691, 1479, 1455, 1391, 1365, 1240, 1169, 1142, 1104, 1014, 985, 958, 923, 876, 772.

HRMS (ESI-TOF): m/z calcd. for $C_{14}H_{25}NNaO_3$ ([M+Na]$^+$) 278.17266, found 278.17250.

Data are consistent with those reported in the literature.[5]

tert-Butyl 2-cyclopropylpyrrolidine-1-carboxylate (27)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), $NiCl_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), bromocyclopropane (40 µL, 0.5 mmol, 1.0 equiv), Boc-Pro-OH (161 mg, 0.75 mmol, 1.5 equiv), K_2CO_3 (138 mg, 1.00 mmol, 2.0 equiv), water (180 µL, 10 mmol, 20 equiv), and 5 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (53 mg, 50%).

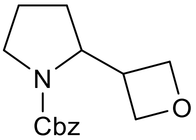
^{1}H-NMR (500 MHz, $CDCl_3$): δ 3.41 – 3.31 (m, 3H), 1.99 – 1.69 (m, 4H), 1.46 (s, 9H), 0.85 (qt, *J* = 8.1, 5.0 Hz, 1H), 0.56 – 0.43 (m, 2H), 0.39 – 0.31 (m, 1H), 0.11 (ddt, *J* = 9.5, 5.8, 4.7 Hz, 1H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 155.2, 79.1, 60.9, 46.7, 31.5, 28.7, 23.5, 16.0, 4.5, 1.8.

IR (film): ν_{max} 3084, 2973, 2879, 1690, 1478, 1453, 1384, 1365, 1272, 1251, 1168, 1105, 1058, 1044, 1017, 985, 946, 928, 908, 867, 819, 771.

HRMS (ESI-TOF): m/z calcd. for $C_{12}H_{21}NNaO_2$ ($[M+Na]^+$) 234.14645, found 234.14643.

Benzyl 2-(oxetan-3-yl)pyrrolidine-1-carboxylate (28)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (10 mg, 8.9 µmol 0.02 equiv), $NiCl_2$•glyme (9.8 mg, 0.045 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (9.60 mg, 0.05 mmol, 0.1 equiv), 3-bromooxetane (37 µL, 0.45 mmol, 1.0 equiv), Cbz-Pro-OH (167 mg, 0.67 mmol, 1.5 equiv), K_2CO_3 (123 mg, 0.89 mmol, 2.0 equiv), water (161 µL, 8.90 mmol, 20 equiv), and 4.5 mL of MeCN were used. The product was isolated by flash chromatography (25% EtOAc/hexanes) as a colorless oil (92 mg, 79%).

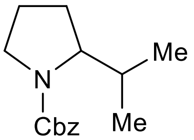
^{1}H-NMR (500 MHz, $CDCl_3$) rotameric mixture: δ 7.39 – 7.29 (m, 5H), 5.17 – 5.03 (m, 2H), 4.87 and 4.72 (2 t, *J* = 6.5 Hz, 1H, rotamer), 4.68 – 4.37 (m, 3H), 4.25 – 4.12 (m, 1H), 3.62 – 3.47 (m, 1H), 3.37 (dt, *J* = 11.3, 6.6 Hz, 1H), 3.30 – 3.11 (m, 1H), 2.01 (dq, *J* = 12.5, 7.7 Hz, 1H), 1.84 (p, *J* = 6.9 Hz, 2H), 1.57 (br s, 1H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 155.6 (155.3), 136.9 (136.4), 128.6 (128.6), 128.4, (128.0) 127.9, 76.6 (76.5), 73.8, (67.3) 66.8, 59.8 (59.2), (47.4) 47.1, 40.2, (29.2) 28.5, 23.9 (23.1).

IR (film): ν_{max} 3563, 2961, 2877, 1696, 1498, 1451,1409, 1356, 1334, 1274, 1244, 1207, 1186, 1102, 1029, 974, 919, 869, 7770, 753, 699.

HRMS (ESI-TOF): m/z calcd. for $C_{15}H_{20}NO_3$ ($[M+H]^+$) 262.14377, found 262.14361.

Benzyl 2-isopropylpyrrolidine-1-carboxylate (29)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (10.0 mg, 9.0 μmol 0.02 equiv), $NiCl_2$•glyme (9.80 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (9.70 mg, 0.05 mmol, 0.1 equiv), 2-bromopropane (42 μL, 0.45 mmol, 1.0 equiv), Cbz-Pro-OH (167 mg, 0.67 mmol, 1.5 equiv), K_2CO_3 (124 mg, 0.90 mmol, 2.0 equiv), water (161 μL, 9.00 mmol, 20 equiv), and 4.5 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (76 mg, 69%).

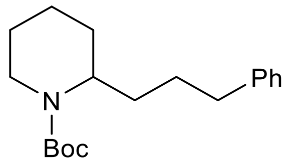
^{1}H-NMR (500 MHz, $CDCl_3$) rotameric mixture: δ 7.42 – 7.27 (m, 5H), 5.19 – 5.06 (m, 2H), 3.84 – 3.72 (m, 1H), 3.68 – 3.59 and 3.59 – 3.51 (2 m, 1H, rotamer), 3.35 – 3.26 (m, 1H), 2.29 – 2.20 and 2.15 – 2.04 (2 m, 1H, rotamer), 1.91 – 1.68 (m, 4H), 0.97 – 0.74 (m, 6H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ (155.7) 155.4, 137.4 (137.2), 128.5, 127.8, 127.9, (66.8) 66.6, 63.1 (62.5), (47.4) 47.1, (30.8) 30.0, (26.6) 25.7, 24.5 (23.8), 19.6, (17.0) 16.8.

IR (film): ν_{max} 3034, 2960, 2874, 1698, 1498, 1455, 1408, 1345, 1332, 1244, 1205, 1184, 1099, 1029, 981, 916, 869, 769, 744, 697.

HRMS (ESI-TOF): m/z calcd. for $C_{15}H_{21}NNaO_2$ ($[M+Na]^+$) 270.14645, found 270.14630.

tert-Butyl 2-(3-phenylpropyl)piperidine-1-carboxylate (30)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(Me)ppy]$_2$(dtbbpy)PF$_6$ (**II**) (10.1 mg, 10.0 μmol, 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-tert-butyl-2,2′-bipyridyl (13.4 mg, 0.05 mmol, 0.1 equiv), Boc-Pip-OH (115 mg, 0.50 mmol, 1.0 equiv), Cs$_2$CO$_3$ (326 mg, 1.00 mmol, 2.0 equiv), and 10 mL MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (360 μL, 20.0 mmol, 40 equiv) and 1-bromo-3-phenylpropane (152 μL, 1.00 mmol, 2.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (2 to 20% EtOAc/hexanes) as a colorless oil (92 mg, 61%).

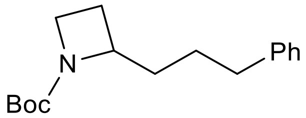
^{1}H-NMR (500 MHz, CD$_3$CN): δ 7.31 – 7.23 (m, 2H), 7.23 – 7.13 (m, 3H), 4.20 (br s, 1H), 3.92 – 3.77 (m, 1H), 2.75 – 2.53 (m, 3H), 1.73 (dtd, *J* = 13.3, 9.3, 5.0 Hz, 1H), 1.59 – 1.41 (m, 8H), 1.39 (s, 9H), 1.35 – 1.24 (m, 1H).

^{13}C-NMR (126 MHz, CD$_3$CN): δ 155.7, 143.8, 129.3, 129.2, 126.6, 79.4, 51.1 (br & weak), 39.4 (br & weak), 36.1, 29.8, 29.3, 29.1, 28.6, 26.5, 19.7.

IR (film): ν_{max} 2974, 2933, 2859, 1686, 1474, 1453, 1415, 1364, 1269, 1254, 1156, 1076, 1045, 870, 767, 748, 699.

HRMS (ESI-TOF): m/z calcd. for $C_{19}H_{29}NNaO_2$ ([M+Na]$^+$) 326.20905, found 326.20920.

tert-Butyl 2-(3-phenylpropyl)azetidine-1-carboxylate (31)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol, 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), Boc-Azetidine-2-Carboxylic Acid (151 mg, 0.75 mmol, 1.5 equiv), K$_2$CO$_3$ (276 mg, 2.00 mmol, 4.0 equiv), 5 mL MeCN, and 5 mL EtOAc. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (180 µL, 10.0 mmol, 20 equiv) and 1-bromo-3-phenylpropane (76 µL, 0.50 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (5 to 7.5% EtOAc/hexanes) as a colorless oil (97 mg, 70%).

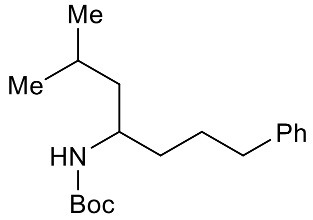
^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.32 – 7.24 (m, 2H), 7.23 – 7.13 (m, 3H), 4.23 – 4.17 (m, 1H), 3.86 – 3.71 (m, 2H), 2.70 – 2.57 (m, 2H), 2.23 (dtd, J = 11.3, 8.8, 5.4 Hz, 1H), 1.95 – 1.87 (m, 1H), 1.80 (ddt, J = 11.3, 9.2, 6.5 Hz, 1H), 1.70 – 1.57 (m, 3H), 1.41 (s, 9H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 156.8, 142.5, 128.5, 128.4, 125.9, 79.2, 62.1, 46.5, 36.0, 35.1, 28.6, 26.5, 22.0.

IR (film): ν_{max} 2974, 2932, 1698, 1454, 1390, 1365, 1254, 1182, 1136, 1099, 749, 699.

HRMS (ESI-TOF): m/z calcd. for $C_{17}H_{25}NNaO_2$ ([M+Na]$^+$) 298.17775, found 298.17812.

tert-Butyl (6-methyl-1-phenylheptan-4-yl)carbamate (32)



According to the general procedure B, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.050 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 1-bromo-3-phenylpropane (76 µL, 0.50 mmol, 1.0 equiv), Boc-Leu-OH (173 mg, 0.75 mmol, 1.5 equiv), Cs$_2$CO$_3$ (326 mg, 1.00 mmol, 2.0 equiv), water (180 µL , 9.7 mmol, 20 equiv), and 10 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (110 mg, 72%).

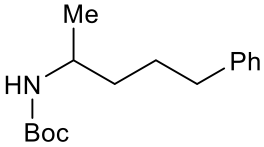
^{1}H-NMR (500 MHz, CDCl$_3$) rotameric mixture: δ 7.31 – 7.24 (m, 3H), 7.21 – 7.14 (m, 3H), 4.17 and 3.89 (br d and br s, *J* = 9.5 Hz, 1H, rotamers), 3.67 and 3.54 (br d and br s, *J* = 7.7 Hz, 1H, rotamers), 2.69 – 2.54 (m, 2H), 1.71 – 1.59 (m, 3H), 1.51 – 1.40 (m, 1H), 1.44 (s, 9H), 1.39 - 1.29 (m, 1H), 1.25 – 1.16 (m, 2H), 0.89 (t, *J* = 6.6 Hz, 6H).

^{13}C-NMR (126 MHz, CDCl$_3$):δ 155.8, 142.6, 128.6, 128.4, 125.8, 79.0, 48.7, 45.2, 36.0, 35.9, 28.6, 27.8, 25.0, 23.3, 22.4.

IR (film): ν_{max} 3346, 2943, 2868, 1690, 1604, 1492, 1454, 1389, 1365, 1247, 1167, 1109, 1086, 1046, 1030, 1006, 946, 874, 777, 746, 698.

HRMS (ESI-TOF): m/z calcd. for $C_{19}H_{31}NNaO_2$ ([M+Na]$^+$) 328.22470, found 328.22444. Data are consistent with those reported in the literature.[10]

tert-Butyl (5-phenylpentan-2-yl)carbamate (33)



According to the general procedure B, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 1-bromo-3-phenylpropane (76 µL, 0.50 mmol, 1.0 equiv), Boc-Ala-OH (142 mg, 0.75 mmol, 1.5 equiv), Cs$_2$CO$_3$ (326 mg, 1.0 mmol, 2.0 equiv), water (180 µL , 9.7 mmol, 20 equiv), and 10 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (94 mg, 71%).

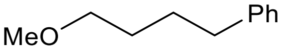
^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.31 – 7.24 (m, 2H), 7.21 – 7.14 (m, 3H), 4.30 (br s, 1H), 3.68 (br s, 1H), 2.67 – 2.56 (m, 2H), 1.70 – 1.61 (m, 2H), 1.44 (s, 11H), 1.10 (d, *J* = 6.6 Hz, 3H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 155.4, 142.3, 128.4, 128.3, 125.7, 79.0, 46.3, 36.9, 35.7, 28.5, 27.9, 21.3.

IR (film): ν_{max} 3343, 2972, 2932, 2861, 1691, 1604, 1498, 1453, 1390, 1365, 1246, 1167, 1105, 1077, 1031, 989, 858, 779, 746, 698.

HRMS (ESI-TOF): m/z calcd. for $C_{16}H_{25}NNaO_2$ ([M+Na]$^+$) 286.17775, found 286.17799.

(4-Methoxybutyl)benzene (34)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.6 mg, 10.3 µmol, 0.02 equiv), $NiCl_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-tert-butyl-2,2′-bipyridyl (13.9 mg, 0.05 mmol, 0.1 equiv), 2-methoxyacetic acid (79 µL, 1.03 mmol, 2 equiv), Cs_2CO_3 (504 mg, 1.55 mmol, 3.0 equiv), and 20 mL MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (112 µL, 6.20 mmol, 12 equiv) and 1-bromo-3-phenylpropane (80 µL, 0.52 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (2% Et_2O/pentane) as a colorless oil (52 mg, 61%).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.31 – 7.24 (m, 2H), 7.22 – 7.14 (m, 3H), 3.39 (t, *J* = 6.3 Hz, 2H), 3.33 (s, 3H), 2.64 (t, *J* = 7.5 Hz, 2H), 1.76 – 1.53 (m, 4H).

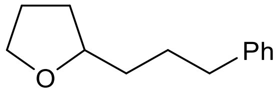
^{13}C-NMR (126 MHz, $CDCl_3$): δ 142.6, 128.5, 128.4, 125.8, 72.8, 58.7, 35.9, 29.4, 28.1.

IR (film): ν_{max} 3063, 3027, 2929, 2859, 2827, 1604, 1496, 1453, 1387, 1174, 1117, 1030, 946, 910, 745.

HRMS (EI-TOF): m/z calcd. for $C_{11}H_{16}O$ ($[M]^{\bullet+}$) 164.1196, found 164.1193.

Data are consistent with those reported in the literature.[11]

2-(3-Phenylpropyl)tetrahydrofuran (35)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.6 mg, 10.3 µmol, 0.02 equiv), NiCl$_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-*tert*-butyl-2,2′-bipyridyl (13.9 mg, 0.05 mmol, 0.1 equiv), tetrahydro-2-furoic acid (124 mg, 1.03 mmol, 2.0 equiv), Cs$_2$CO$_3$ (420 mg, 1.29 mmol, 2.5 equiv), 7 mL of EtOAc and 3 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (56 µL, 3.10 mmol, 6.0 equiv) and 1-bromo-3-phenylpropane (80 µL, 0.52 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (0 to 5% Et$_2$O/pentane) as a colorless oil (73 mg, 74%).

^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.29 – 7.24 (m, 2H), 7.21 – 7.15 (m, 3H), 3.88 – 3.77 (m, 2H), 3.71 (td, *J* = 7.9, 6.3 Hz, 1H), 2.70 – 2.59 (m, 2H), 2.00 – 1.92 (m, 1H), 1.91 – 1.71 (m, 3H), 1.71 – 1.57 (m, 2H), 1.56 – 1.36 (m, 2H).

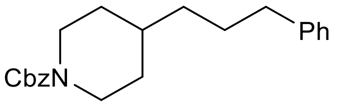
^{13}C-NMR (126 MHz, CDCl$_3$): δ 142.6, 128.5, 128.4, 125.8, 79.3, 67.8, 36.1, 35.4, 31.5, 28.3, 25.8.

IR (film): ν_{max} 3026, 2933, 2858, 1603, 1496, 1454, 1067, 1029, 919, 747

HRMS (EI-TOF): m/z calcd. for $C_{13}H_{18}O$ ($[M]^{\bullet+}$) 190.1352, found 190.1354.

Data are consistent with those reported in the literature.[12]

Benzyl 4-(3-phenylpropyl)piperidine-1-carboxylate (36)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.6 mg, 10.3 µmol, 0.02 equiv), NiCl$_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-*tert*-butyl-2,2′-bipyridyl (13.9 mg, 0.05 mmol, 0.1 equiv), Cbz-Inp-OH (272 mg, 1.03 mmol, 2.0 equiv), Cs$_2$CO$_3$ (420 mg, 1.29 mmol, 2.5 equiv), and 10 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (56 µL, 3.10 mmol, 6.0 equiv) and 1-bromo-3-phenylpropane (80 µL, 0.52 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred (300 rpm) and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) with a fan placed above for cooling. After 26 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (0 to 1% EtOAc/toluene) as a colorless oil (107 mg, 62%).

^{1}H-NMR (500 MHz, CDCl$_3$): rotameric mixture δ 7.40 – 7.35 (m, 4H), 7.35 – 7.27 (m, 3H), 7.23 – 7.16 (m, 3H), 5.14 (s, 2H), 4.17 (br s, 2H), 2.76 (br s, 2H), 2.61 (t, *J* = 7.7 Hz, 2H), 1.76 – 1.59 (m, 4H), 1.49 – 1.37 (m, 1H), 1.34 – 1.26 (m, 2H), 1.11 (br s, 2H).

^{13}C-NMR (126 MHz, CDCl$_3$): rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 155.4, 142.6, 137.1, 128.5, 128.4, 128.4, 128.0, 127.9, 125.8, 67.0, 44.4, 36.2*, 35.9, (32.2) 32.1, 28.6.

IR (film): ν_{max} 3027, 2928, 2853, 1697, 1497, 1429, 1363, 1277, 1232, 1163, 1120, 1082, 1020, 965, 748, 698.

HRMS (ESI-TOF): m/z calcd. for $C_{22}H_{27}NNaO_2$ ([M+Na]$^+$) 360.19340, found 360.19353.
Data are consistent with those reported in the literature.[13]

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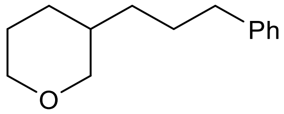
* This peak corresponds to two coincident ^{13}C signals

3-(3-Phenylpropyl)tetrahydro-2*H*-pyran (37)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.6 mg, 10.3 μmol, 0.02 equiv), NiCl$_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-*tert*-butyl-2,2′-bipyridyl (13.9 mg, 0.05 mmol, 0.1 equiv), tetrahydro-*2H*-pyran-3-carboxylic acid (134 mg, 1.03 mmol, 2.0 equiv), Cs$_2$CO$_3$ (504 mg, 1.29 mmol, 3.0 equiv) and 10 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (56 μL, 3.10 mmol, 6.0 equiv) and 1-bromo-3-phenylpropane (80 μL, 0.52 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) in a water bath with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (2 to 5% EtOAc/hexanes) as a light yellow oil (70 mg, 66%).

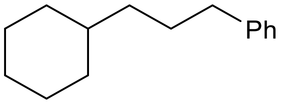
^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.31 – 7.26 (m, 2H), 7.21 – 7.14 (m, 3H), 3.91 – 3.82 (m, 2H), 3.33 (ddd, *J* = 11.0, 9.5, 4.0 Hz, 1H), 3.03 (dd, *J* = 11.2, 10.1 Hz, 1H), 2.59 (t, *J* = 7.7 Hz, 2H), 1.91 – 1.82 (m, 1H), 1.70 – 1.53 (m, 5H), 1.30 – 1.04 (m, 3H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 142.6, 128.5, 128.4, 125.8, 73.6, 68.6, 36.2, 36.0, 32.2, 30.1, 28.6, 26.0.

IR (film): ν_{max} 3026, 2929, 2846, 1603, 1496, 1453, 1278, 1186, 1093, 1035, 944, 907, 873, 856, 747.

HRMS (EI-TOF): m/z calcd. for $C_{14}H_{20}O$ ($[M]^{\bullet+}$) 204.1509, found 204.1512

(3-Cyclohexylpropyl)benzene (38)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.6 mg, 10.3 µmol, 0.02 equiv), $NiCl_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-*tert*-butyl-2,2′-bipyridyl (13.9 mg, 0.05 mmol, 0.1 equiv), cyclohexanecarboxylic acid (132 mg, 1.03 mmol, 2.0 equiv), Cs_2CO_3 (504 mg, 1.29 mmol, 3.0 equiv), 14 mL of EtOAc and 6 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (140 µL, 7.70 mmol, 15 equiv) and 1-bromo-3-phenylpropane (80 µL, 0.52 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) in a water bath with a fan placed above for cooling. After 24 h, an additional portion of Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (11.6 mg, 10.3 µmol, 0.02 equiv) was added in a minimal amount of MeCN. After a further 24 h of irradiation, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (pentane) as a colorless oil (54 mg, 52%).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.30 – 7.24 (m, 2H), 7.21 – 7.14 (m, 3H), 2.58 (t, *J* = 7.6 Hz, 2H), 1.75 – 1.56 (m, 7H), 1.29 – 1.07 (m, 6H), 0.93 – 0.79 (m, 2H).

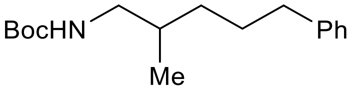
^{13}C-NMR (126 MHz, $CDCl_3$): δ 143.1, 128.5, 128.3, 125.7, 37.7, 37.3, 36.4, 33.5, 29.0, 26.9, 26.6.

IR (film): ν_{max} 3027, 2921, 2850, 1496, 1449, 745, 697.

HRMS (EI-TOF): m/z calcd. for $C_{15}H_{22}$ ($[M]^{\bullet+}$) 202.1716, found 202.1719

Data are consistent with those reported in the literature.[13]

***tert*-Butyl (2-methyl-5-phenylpentyl)carbamate (39)**



An oven dried 8 mL vial equipped with a Teflon septum and magnetic stir bar was charged with Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.6 mg, 10.3 μmol, 0.02 equiv), NiCl$_2$•glyme (11.3 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-*tert*-butyl-2,2′-bipyridyl (13.9 mg, 0.05 mmol, 0.1 equiv), 3-((*tert*-butoxycarbonyl)amino)-2-methylpropanoic acid (210 mg, 1.03 mmol, 2.0 equiv), Cs$_2$CO$_3$ (504 mg, 1.29 mmol, 3.0 equiv), 3.5 mL of EtOAc and 1.5 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (28 μL, 1.55 mmol, 3.0 equiv) and 1-bromo-3-phenylpropane (80 μL, 0.52 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) in a water bath with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (0 to 0.5% EtOAc/toluene) as a colorless oil (83 mg, 58%).

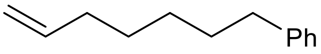
^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.30 – 7.24 (m, 2H), 7.21 – 7.13 (m, 3H), 4.52 (br s, NH), 3.12 – 2.97 (m, 1H), 2.96 – 2.81 (m, 1H), 2.65 – 2.53 (m, 2H), 1.74 – 1.54 (m, 3H), 1.44 (s, 9H), 1.42 – 1.34 (m, 1H), 1.20 – 1.10 (m, 1H), 0.88 (d, *J* = 6.7 Hz, 3H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 156.2, 142.6, 128.5, 128.4, 125.8, 79.1, 46.7, 36.2, 33.9, 33.7, 28.9, 28.5, 17.6.

IR (film): ν_{max} 3353, 2930, 1695, 1512, 1454, 1391, 1365, 1248, 1170, 996, 748, 699.

HRMS (ESI-TOF): m/z calcd. for $C_{17}H_{27}NNaO_2$ ([M+Na]$^+$) 300.19340, found 300.19326

Hept-6-en-1-ylbenzene (40)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(F)ppy]$_2$(dtbbpy)PF$_6$ (**III**) (11.7 mg, 11.0 μmol, 0.02 equiv), NiCl$_2$•glyme (12.6 mg, 0.06 mmol, 0.1 equiv), 4,4′-di-methyl-2,2′-bipyridyl (10.6 mg, 0.06 mmol, 0.1 equiv), cyclopropylacetic acid (107 μL, 115 mg, 1.15 mmol, 2.0 equiv), Cs$_2$CO$_3$ (560 mg, 1.72 mmol, 3.0 equiv), 11 mL of EtOAc and 11 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (155 μL, 8.60 mmol, 15 equiv) and 1-bromo-3-phenylpropane (87 μL, 0.57 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) in a water bath with a fan placed above for cooling. After 24 h, an additional portion of Ir[dF(F)ppy]$_2$(dtbbpy)PF$_6$ (**III**) (11.7 mg, 11.0 μmol, 0.02 equiv) was added in a minimal amount of MeCN. After a further 24 h of irradiation, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (pentane) as a colorless oil (43 mg, 43%).

^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.31 – 7.23 (m, 2H), 7.21 – 7.13 (m, 3H), 5.81 (ddt, *J* = 16.9, 10.3, 6.7 Hz, 1H), 5.05 – 4.83 (m, 2H), 2.61 (t, *J* = 7.9 Hz, 2H), 2.05 (q, *J* = 7.1 Hz, 2H), 1.63 (p, *J* = 7.5 Hz, 2H), 1.46 – 1.31 (m, 4H).

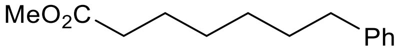
^{13}C-NMR (126 MHz, CDCl$_3$): δ 143.0, 139.2, 128.5, 128.4, 125.7, 114.4, 36.1, 33.9, 31.5, 29.0, 28.9.

IR (film): ν_{max} 3064, 3028, 2928, 2855, 1641, 1605, 1496, 1454, 1030, 993, 909, 745.

HRMS (EI-TOF): m/z calcd. for $C_{13}H_{18}$ ($[M]^{\bullet+}$) 174.1403, found 174.1402

Data are consistent with those reported in the literature.[15]

Methyl 7-phenylheptanoate (41)



An oven dried 40 mL vial equipped with a Teflon septum and cross-shape magnetic stir bar was charged with Ir[dF(F)ppy]$_2$(dtbbpy)PF$_6$ (**III**) (11.7 mg, 11.0 μmol, 0.02 equiv), NiCl$_2$•glyme (12.6 mg, 0.06 mmol, 0.1 equiv), 4,4′-di-methyl-2,2′-bipyridyl (10.6 mg, 0.06 mmol, 0.1 equiv), mono-Methyl glutarate (143 μL, 167 mg, 1.15 mmol, 2.0 equiv), Cs_2CO_3 (560 mg, 1.72 mmol, 3.0 equiv), and 23 mL of MeCN. The reaction mixture was degassed by bubbling nitrogen stream for 15 min at 0 °C. Water (155 μL, 8.60 mmol, 15 equiv) and 1-bromo-3-phenylpropane (87 μL, 0.57 mmol, 1.0 equiv) were then added. The reaction mixture was then stirred and irradiated with two 34 W blue LEDs (vials approximately 6 cm away from the light source) in a water bath with a fan placed above for cooling. After 24 h, the reaction mixture was diluted with EtOAc, filtered, and concentrated in vacuo. The product was isolated by flash chromatography (2% Et2O/pentane) as a colorless oil (50 mg, 40%).

^{1}H-NMR (500 MHz, CDCl$_3$): δ 7.31 – 7.23 (m, 2H), 7.21 – 7.13 (m, 3H), 3.66 (s, 3H), 2.60 (t, *J* = 7.7 Hz, 2H), 2.30 (t, *J* = 7.5 Hz, 2H), 1.68 – 1.57 (m, 4H), 1.40 – 1.28 (m, 4H).

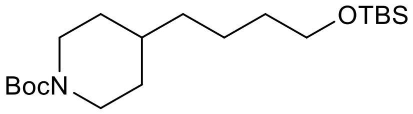
^{13}C-NMR (126 MHz, CDCl$_3$): δ 174.4, 142.8, 128.5, 128.4, 125.7, 51.6, 36.0, 34.2, 31.4, 29.1, 29.0, 25.0.

IR (film): ν_{max} 3027, 2930, 2857, 1738, 1604, 1496, 1454, 1436, 1361, 1251, 1197, 1171, 1093, 1015, 879, 747, 699.

HRMS (ESI-TOF): m/z calcd. for $C_{14}H_{21}O_2$ ([M+H]$^+$) 221.15361, found 221.15362

Data are consistent with those reported in the literature.[14]

tert-Butyl 4-(4-((*tert*-butyldimethylsilyl)oxy)butyl)piperidine-1-carboxylate



According to the procedure as for **36**, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol, 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.050 mmol, 0.1 equiv), 4,4′-di-tertbutyl-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), (4-bromobutoxy)(tert-butyl)dimethylsilane (100 mg, 0.5 mmol, 1.0 equiv), 1-(*tert*-butoxycarbonyl)piperidine-4-carboxylic acid (229 mg, 1.00 mmol, 2.0 equiv), Cs$_2$CO$_3$ (407 mg, 1.25 mmol, 2.5 equiv), water (54 µL, 3.00 mmol, 6.0 equiv), and 10 mL of MeCN were used. The product was isolated by flash chromatography (3% EtOAc/hexanes) as a colorless oil (118 mg, 64%).

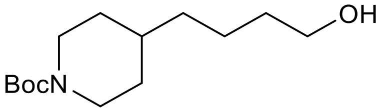
^{1}H-NMR (500 MHz, CDCl$_3$): δ 4.06 (br s, 2H), 3.60 (t, *J* = 6.5 Hz, 2H), 2.66 (br s, 2H), 1.64 (br d, *J* = 13.2 Hz, 2H), 1.54 – 1.41 (m, 11H), 1.40 – 1.29 (m, 3H), 1.27 – 1.20 (m, 2H), 1.13 – 1.00 (m, 2H), 0.89 (s, 9H), 0.04 (s, 6H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 155.1, 79.3, 63.3, 44.5, 43.8, 36.5, 36.1, 33.1, 32.3, 28.6, 26.1, 23.0, 18.5, -5.1.

IR (film): ν_{max} 2929, 2856, 1695, 1472, 1420, 1390, 1365, 1277, 1243, 1166, 1096, 1045, 1006, 960, 937, 834, 773, 661.

HRMS (ESI-TOF): m/z calcd. for $C_{20}H_{41}NNaO_3Si$ ([M+Na]$^+$) 394.27479, found 394.27435.

tert-Butyl 4-(4-hydroxybutyl)piperidine-1-carboxylate (44)



tert-Butyl 4-(4-((*tert*-butyldimethylsilyl)oxy)butyl)piperidine-1-carboxylate (380 mg, 1.02 mmol) was dissolved in dry THF (5 ml) and cooled to 0 °C. TBAF (1 M in THF, 1.50 ml, 1.50 mmol, 1.5 equiv) was slowly added and the mixture was allowed to stir over night at room temperature, quenched by the addition of aq. NH_4Cl (sat, 10 ml) and the aqueous phase was extracted with DCM (3x). The combined organic phases were dried over Na_2SO_4 and the solvent removed. The product was isolated by flash chromatography (33% EtOAc/hexanes) as yellow oil (246 mg, 93%).

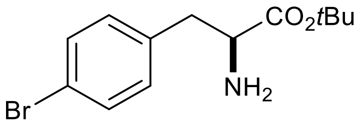
^{1}H-NMR (500 MHz, $CDCl_3$): δ 4.06 (br s, 2H), 3.64 (t, *J* = 6.6 Hz, 2H), 2.66 (br s, 2H), 1.64 (d, *J* = 13.1 Hz, 2H), 1.60 – 1.51 (m, 2H), 1.45 (s, 9H), 1.42 – 1.33 (m, 3H), 1.31 – 1.20 (m, 3H), 1.07 (qd, *J* = 12.4, 4.3 Hz, 2H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 155.1, 79.3, 63.1, 44.2 (br & weak), 36.4, 36.1, 33.1, 32.3 (br), 28.6, 23.0.

IR (film): ν_{max} 3425, 1927, 2854, 1692, 1669, 1422, 1366, 1277, 1240, 1159, 1067, 1035, 977, 962, 943, 865, 822, 769.

HRMS (ESI-TOF): m/z calcd. for $C_{14}H_{27}NNaO_3$ ($[M+Na]^+$) 280.18831, found 280.18863.

***tert*-Butyl (*S*)-2-amino-3-(4-bromophenyl)propanoate**



(*S*)-2-amino-3-(4-bromophenyl)propanoic acid (2.00 g, 8.19 mmol) was suspended in *t*BuOAc (22 ml), cooled to 0 °C and $HClO_4$ (70%, 1.10 ml, 13.1 mmol, 1.5 equiv) was added slowly under N_2 and the resulting clear solution was stirred over night at room temperature. The solution was washed with water and aq. HCl (1 M), the combined aqueous phases were basified with aq. K_2CO_3 (10%) to pH 9 and extracted with DCM (4x). The organic phases were washed with brine, dried over Na_2SO_4 and the solvent removed. The product was isolated as colorless oil and used for the next step without further purification (1.62 g, 66%).

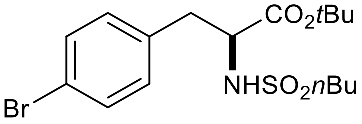
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.3 Hz, 2H), 7.10 (d, *J* = 8.3 Hz, 2H), 3.57 (t, *J* = 6.7 Hz, 1H), 2.98 (dd, *J* = 13.6, 5.7 Hz, 1H), 2.79 (dd, *J* = 13.6, 7.7 Hz, 1H), 1.43 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 174.3, 136.8, 131.6, 131.3, 120.7, 81.5, 56.3, 40.7, 28.2.

IR (film): ν_{max} 3382, 2977, 2932, 1725, 1592, 1488, 1456, 1393, 1367, 1283, 1248, 1149, 1072, 1012, 843, 800, 747, 712.

HRMS (ESI-TOF): m/z calcd. for $C_{13}H_{19}BrNO_2$ ($[M+H]^+$) 300.05937, found 300.05946.

tert-Butyl (S)-3-(4-bromophenyl)-2-(butylsulfonamido)propanoate



tert-Butyl (*S*)-2-amino-3-(4-bromophenyl)propanoate (1.00 g, 3.33 mmol) was dissolved in DCM (17 ml) and cooled to 0 °C. Triethylamine (0.93 ml, 6.66 mmol, 2.0 equiv) was added followed by dropwise addition of butane-1-sulfonyl chloride (0.65 ml, 5.00 mmol, 1.5 equiv). The clear solution was stirred 2 h at room temperature and after completion (TLC) quenched by the addition of aq. HCl (1 M). The phases were separated, the organic phase washed with aq. $NaHCO_3$ (sat.) and brine, dried over Na_2SO_4 and evaporated to dryness. The product was isolated by flash chromatography (20% EtOAc/hexanes) as yellow oil (1.20 g, 86%).

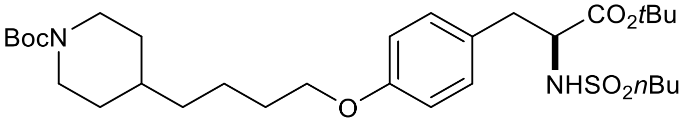
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.44 (d, *J* = 8.3 Hz, 2H), 7.10 (d, *J* = 8.4 Hz, 2H), 4.74 (d, *J* = 9.2 Hz, 1H), 4.20 (ddd, *J* = 9.2, 7.0, 5.8 Hz, 1H), 3.05 (dd, *J* = 13.9, 5.8 Hz, 1H), 2.95 (dd, *J* = 13.9, 7.0 Hz, 1H), 2.77 (t, *J* = 8.1 Hz, 2H), 1.72 – 1.58 (m, 2H), 1.44 (s, 9H), 1.33 (h, *J* = 7.5 Hz, 2H), 0.89 (t, *J* = 7.4 Hz, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 170.5, 134.9, 131.8, 131.5, 121.4, 83.4, 57.4, 53.6, 39.4, 28.1, 25.5, 21.6, 13.7.

IR (film): ν_{max} 3274, 2964, 2934, 2875, 1729, 1489, 1456, 1407, 1394, 1368, 1327, 1277, 1258, 1143, 1112, 1072, 1012, 956, 937, 840, 812, 766, 748, 712.

HRMS (ESI-TOF): m/z calcd. for $C_{17}H_{26}BrNNaO_4$ ($[M+Na]^+$) 442.06581, found 442.06602.

***tert*-butyl (S)-4-(4-(4-(3-(tert-butoxy)-2-(butylsulfonamido)-3-oxopropyl)phenoxy)butyl) piperidine-1-carboxylate**



tert-Butyl (*S*)-3-(4-bromophenyl)-2-(butylsulfonamido)propanoate (168 mg, 0.40 mmol) was weighed into an 8 ml oven dried vial and evacuated for 30 min. K_2CO_3 (55.0 mg, 0.40 mmol, 1.0 equiv) was added, followed by a solution of Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (4.50 mg, 4.00 µmol 0.01 equiv), $NiCl_2$•glyme (8.79 mg, 0.04 mmol, 0.1 equiv), 4,4′-di-tertbutyl-2,2′-bipyridyl (10.7 mg, 0.04 mmol, 0.1 equiv) and Quinuclidine (4.45 mg, 0.04 mmol, 0.1 equiv) in acetonitrile (1.5 ml). *Tert*-Butyl 4-(4-hydroxybutyl)piperidine-1-carboxylate **43** (154 mg, 0.60 mmol, 1.5 equiv) was added in acetonitrile (0.5 ml) and the mixture was evacuated and cooled to -78 °C. After evacuating for 5 min the vial was backfilled with nitrogen and warmed to room temperature. This process was repeated three times, then the vial was sealed with parafilm, placed 1 cm away from 3 blue LED strips, and irradiated under fan cooling. After 48 h, EtOAc (10 ml) and water (10 ml) was added, the phases separated and the aqueous phase extracted with EtOAc (5x). The combined organic phases were washed with brine, dried over Na2SO4 and evaporated to dryness. The product was isolated by flash chromatography (10% EtOAc/hexanes) as colorless oil (146 mg, 60%). In addition non reacted aryl bromide was reisolated (57 mg, 34%).

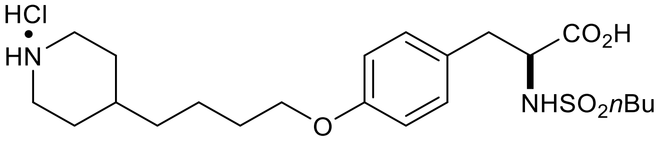
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.11 (d, J = 8.5 Hz, 2H), 6.82 (d, J = 8.5 Hz, 2H), 4.68 (d, J = 9.3 Hz, 1H), 4.18 (ddd, J = 9.1, 6.9, 5.7 Hz, 1H), 4.07 (br s, 2H), 3.92 (t, J = 6.4 Hz, 2H), 3.03 (dd, J = 13.9, 5.6 Hz, 1H), 2.93 (dd, J = 13.9, 7.0 Hz, 1H), 2.78 – 2.71 (m, 2H), 2.67 (br s, 2H), 1.76 (p, J = 6.7 Hz, 2H), 1.69 – 1.59 (m, 4H), 1.53 – 1.37 (m, 20H), 1.30 (p, J = 7.3 Hz, 5H), 1.08 (qd, J = 12.4, 4.3 Hz, 2H), 0.87 (t, J = 7.3 Hz, 3H).

^{13}C-NMR (126 MHz, $CDCl_3$): δ 170.9, 158.5, 155.1, 130.8, 127.6, 114.7, 83.0, 79.3, 68.0, 57.8, 53.6, 39.0, 36.4, 36.1, 32.3, 29.6, 28.6, 28.1, 25.5, 23.3, 21.6, 13.6.

IR (film): ν_{max} 3270, 2932, 2866, 1732, 1690, 1613, 1513, 1424, 1393, 1366, 1328, 1300, 1277, 1245, 1145, 1116, 1032, 962, 914, 841, 769, 730.

HRMS (ESI-TOF): m/z calcd. for $C_{31}H_{52}N_2NaO_7S$ ([M+Na]$^+$) 619.33874, found 619.33839.

(*S*)-2-(butylsulfonamido)-3-(4-(4-(piperidin-4-yl)butoxy)phenyl) propanoic acid hydrochloride (Tirofiban, 45)



tert-butyl (S)-4-(4-(4-(3-(tert-butoxy)-2-(butylsulfonamido)-3-oxopropyl)phenoxy)butyl) piperidine-1-carboxylate (50.0 mg, 0.08 mmol) was dissolved in DCM (0.5 ml) and cooled to 0 °C. Under vigorous stirring, HCl (4 M in Dioxane, 0.84 ml, 3.35 mmol, 40 equiv) was added and the mixture stirred over night at room temperature. The solution was sparged with nitrogen to remove excess HCl and evaporated to dryness. The resulting gum was layered with Et_2O, and the precipitate was dried on high vacuum and washed thoroughly with Et_2O. The product was isolated by decantation as colorless solid (39.0 mg 98%).

^{1}H-NMR (500 MHz, CD_3OD): 7.19 (d, *J* = 8.2 Hz, 2H), 6.85 (d, *J* = 8.2 Hz, 2H), 4.09 (dd, *J* = 9.7, 4.7 Hz, 1H), 3.97 (t, *J* = 6.2 Hz, 2H), 3.36 (d, *J* = 12.9 Hz, 2H), 3.11 (dd, *J* = 13.9, 4.7 Hz, 1H), 2.95 (td, *J* = 13.0, 3.0 Hz, 2H), 2.78 (dd, *J* = 13.8, 9.7 Hz, 1H), 2.66 (ddd, *J* = 9.0, 6.2, 2.0 Hz, 2H), 1.96 (d, *J* = 12.5 Hz, 2H), 1.78 (p, *J* = 6.6 Hz, 2H), 1.68 – 1.58 (m, 1H), 1.53 (dtd, *J* = 18.6, 11.4, 9.0, 5.4 Hz, 3H), 1.42 – 1.29 (m, 5H), 1.28 – 1.20 (m, 2H), 0.85 (t, *J* = 7.3 Hz, 3H).

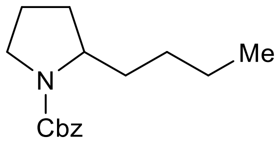
^{13}C-NMR (126 MHz, CD_3OD): δ 175.2, 159.5, 131.7, 130.5, 115.4, 68.7, 59.5, 54.1, 45.4, 39.1, 36.8, 34.8, 30.4, 30.1, 26.5, 24.0, 22.5, 13.9.

IR (film): ν_{max} 2934, 2871, 1730, 1612, 1512, 1455, 1379, 1299, 1243, 1177, 1140, 1115, 1077, 1040, 958, 836, 731.

HRMS (ESI-TOF): m/z calcd. for $C_{22}H_{37}N_2O_5S$ ($[M+H]^+$) 441.24177, found 441.24123.

Data are consistent with those reported in the literature.[16]

Benzyl 2-butylpyrrolidine-1-carboxylate (46)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (10.5 mg, 9.3 µmol 0.02 equiv), $NiCl_2$•glyme (10.2 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.1 mg, 0.05 mmol, 0.1 equiv), bromobutane (50 µL, 0.47 mmol, 1.0 equiv), Cbz-Pro-OH (174 mg, 0.70 mmol, 1.5 equiv), K_2CO_3 (129 mg, 0.93 mmol, 2.0 equiv), water (168 µL, 9.3 mmol, 20 equiv), and 4.7 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (93 mg, 76%).

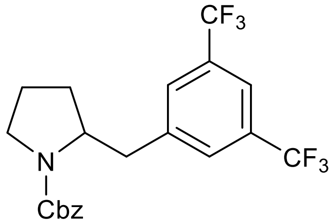
^{1}H-NMR (500 MHz, $CDCl_3$) rotameric mixture: δ 7.45 – 7.27 (m, 5H), 5.22 – 5.07 (m, 2H), 3.88 – 3.79 (m, 1H), 3.54 – 3.32 (m, 2H), 1.98 – 1.75 (m, 4H), 1.72 – 1.63 (m, 1H), 1.40 – 1.11 (m, 5H), 0.89 and 0.84 (2 t, *J* = 7.0 Hz, 3H, rotamer).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ (155.2) 155.0, 137.3 (137.2), 128.5, 127.9, (66.7) 66.5, 58.2 (57.5), (46.7) 46.4, (34.4) 33.7, 30.7 (29.9), 28.6 (28.5), 23.9 (23.2), 22.9 (22.7), 14.3 (14.2).

IR (film): ν_{max} 3033, 2955, 2930, 2872, 1698, 1498, 1453, 1409, 1356, 1335, 1249, 1213, 1186, 1099, 1029, 983, 914, 866, 769, 739, 697.

HRMS (ESI-TOF): m/z calcd. for $C_{16}H_{23}NNaO_2$ ($[M+Na]^+$) 284.16210, found 284.16200.

Benzyl 2-(3,5-bis(trifluoromethyl)benzyl)pyrrolidine-1-carboxylate (47)



According to the general procedure A, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (7.90 mg, 7.00 µmol 0.02 equiv), NiCl$_2$•glyme (7.70 mg, 0.04 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (7.60 mg, 0.04 mmol, 0.1 equiv), 1-(chloromethyl)-3,5-bis(trifluoromethyl)benzene (92 mg, 0.35 mmol, 1.0 equiv), Cbz-Pro-OH (131 mg, 0.53 mmol, 1.5 equiv), K$_2$CO$_3$ (97.0 mg, 0.70 mmol, 2.0 equiv), water (126 µL, 7.00 mmol, 20 equiv), and 3.5 mL of MeCN were used. The product was isolated by flash chromatography (5% EtOAc/hexanes) as a colorless oil (89 mg, 59%).

^{1}H-NMR (500 MHz, CDCl$_3$) rotameric mixture: δ 7.76 7.65 (m, 2H), 7.50 (s, 1H), 7.42 – 7.30 (m, 5H), 5.21 – 5.11 (m, 2H), 4.11 and 4.04 (2 br s, 1H, rotamer), 3.54 – 3.11 (m, 3H), 2.77 and 2.65 (2 dd, *J* = 13.1, 9.4 Hz, 1H), 1.96 – 1.56 (m, 4H).

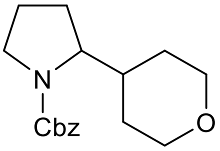
^{13}C-NMR (126 MHz, CDCl$_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 155.1 (154.9), 141.5, 137.0 (136.5), (131.8 (q, *J* = 33.5 Hz)) 131.7 (q, *J* = 32.7 Hz), 129.7 – 128.0 (m), 123.5 (q, *J* = 272.8 Hz) (123.4 (q, *J* = 273.1 Hz)), 120.6, (67.4) 66.9, 58.9 (58.7), (47.0) 46.8, (40.8) 39.4, (30.1) 29.2, 23.7 (22.9).

^{19}F-NMR (282 MHz, CDCl$_3$): δ −62.8.

IR (film): ν_{max} 3037, 2962, 2882, 1698, 1622, 1499, 1454, 1311, 1379, 1357, 1338, 1277, 1170, 1127, 1089, 1030, 977, 934, 897, 844, 770, 735, 707, 698, 683.

HRMS (ESI-TOF): m/z calcd. for $C_{21}H_{20}F_6NO_2$ ([M+H]$^+$) 432.13927, found 432.14008.

Benzyl 2-(tetrahydro-2*H*-pyran-4-yl)pyrrolidine-1-carboxylate (48)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (9.30 mg, 8.30 µmol 0.02 equiv), $NiCl_2$•glyme (9.10 mg, 0.04 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (9.00 mg, 0.041 mmol, 0.1 equiv), 4-bromotetrahydro-2*H*-pryan (47 µL, 0.42 mmol, 1.0 equiv), Cbz-Pro-OH (155 mg, 0.62 mmol, 1.5 equiv), K_2CO_3 (115 mg, 0.83 mmol, 2.0 equiv), water (150 µL, 8.30 mmol, 20 equiv), and 4.2 mL of MeCN were used. The product was isolated by flash chromatography (15% EtOAc/hexanes) as a colorless oil (100 mg, 83%).

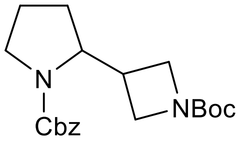
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.41 – 7.28 (m, 5H), 5.24 – 5.05 (m, 2H), 4.03 – 3.89 (m, 2H), 3.88 – 3.73 (m, 1H), 3.66 – 3.47 (m, 1H), 3.42 – 3.17 (m, 3H), 2.16 – 2.02 (m, 1H), 1.92 – 1.73 (m, 4H), 1.55 – 1.23 (m, 4H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ (155.6) 155.5, 137.2 (137.0), 128.6, 128.2 (128.1), (128.0) 127.9, (68.3) 68.1, (67.0) 66.7, 61.9 (61.4), (47.1) 47.0, (38.9) 38.1, (30.1) 30.1, (28.2) 27.8, (27.4) 26.5, 24.5 (23.6).

IR (film): ν_{max} 2949, 2843, 1698, 1498, 1455, 1409, 1354, 1332, 1269, 1238, 1184, 1139, 1100, 1014, 985, 920, 832, 770, 750, 698.

HRMS (ESI-TOF): m/z calcd. for $C_{17}H_{24}NO_3$ ($[M+H]^+$) 290.17507, found 290.17507.

Benzyl 2-(1-(*tert*-butoxycarbonyl)azetidin-3-yl)pyrrolidine-1-carboxylate (49)



According to the general procedure A, Ir[dF(CF_3)ppy]$_2$(dtbbpy)PF_6 (**I**) (8.20 mg, 7.30 µmol 0.02 equiv), $NiCl_2$•glyme (8.10 mg, 0.04 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (7.90 mg, 0.04 mmol, 0.1 equiv), 3-bromo-Boc-azetidine (87.0 mg, 0.37 mmol, 1.0 equiv), Cbz-Pro-OH (137 mg, 0.55 mmol, 1.5 equiv), K_2CO_3 (101 mg, 0.73 mmol, 2.0 equiv), water (132 µL, 7.30 mmol, 20 equiv), and 3.7 mL of MeCN were used. The product was isolated by preparative SFC as a colorless oil (65 mg, 50%).

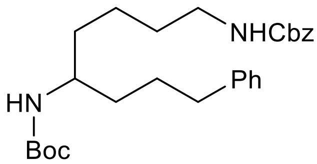
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.42 – 7.29 (m, 5H), 5.19 – 5.03 (m, 2H), 4.17 – 3.73 (m, 4H), 3.69 – 3.47 (m, 2H), 3.41 – 3.30 (m, 1H), 2.87 – 2.65 (m, 1H), 2.06 – 1.93 (m, 1H), 1.92 – 1.79 (m, 2H), 1.70 – 1.59 (m, 1H), 1.42 (s, 9H).

^{13}C-NMR (126 MHz, $CDCl_3$) rotameric mixture, resonances for minor rotamer are enclosed in parenthesis (): δ 156.4, 155.6 (155.3), 136.9 (136.5), 128.5, (128.3) 128.0, 127.9, 79.3, (67.2) 66.8, 60 (59.3), 54.0, 50.6, (47.3) 47.1, 33.0, (28.8) 28.0, 28.5, 23.8 (23.1)

IR (film): ν_{max} 2971, 2884, 1693, 1479, 1453, 1404, 1360, 1250, 1128, 1099, 1025, 972, 918, 863, 770, 753, 698.

HRMS (ESI-TOF): m/z calcd. for $C_{20}H_{28}NS_2NaO_4$ ($[M+Na]^+$) 383.19413, found 383.19438.

Benzyl *tert*-butyl (8-phenyloctane-1,5-diyl)dicarbamate (50)



According to the general procedure B, Ir[dF(CF$_3$)ppy]$_2$(dtbbpy)PF$_6$ (**I**) (11.2 mg, 10.0 µmol 0.02 equiv), NiCl$_2$•glyme (11.0 mg, 0.05 mmol, 0.1 equiv), 4,4′-di-methoxy-2,2′-bipyridyl (10.8 mg, 0.05 mmol, 0.1 equiv), 1-bromo-3-phenylpropane (76 µL, 0.50 mmol, 1.0 equiv), Boc-Lys(Cbz)-OH (285 mg, 0.75 mmol, 1.5 equiv), Cs$_2$CO$_3$ (326 mg, 1.0 mmol, 2.0 equiv), water (180 µL, 9.70 mmol, 20 equiv), and 10 mL of MeCN were used. The product was isolated by flash chromatography (20% EtOAc/hexanes) as a colorless solid (144 mg, 65%).

^{1}H-NMR (500 MHz, CDCl$_3$) rotameric mixture: δ 7.37 – 7.34 (m, 3H), 7.34 – 7.30 (m, 1H), 7.31 – 7.24 (m, 3H), 7.20 – 7.15 (m, 3H), 5.18 – 5.05 (m, 2H), 4.81 and 4.72 (2 br s, 1H, rotamers), 4.24 and 4.17 (d and br s, *J* = 9.3 Hz, 1H, rotamers), 3.57 and 3.43 (2 br s, 1H), 3.18 (q, *J* = 6.7 Hz, 2H), 2.69 – 2.54 (m, 2H), 1.73 – 1.57 (m, 3H), 1.57 – 1.24 (m, 16H).

^{13}C-NMR (126 MHz, CDCl$_3$): δ 156.6, 156.0, 142.4, 136.8, 128.6, 128.6, 128.4, 128.3, 128.2, 125.9, 79.2, 77.2, 66.7, 50.3, 41.0, 35.8, 35.4, 35.4, 29.8, 28.6, 27.9, 23.0.

IR (film): ν_{max} 3366, 2980, 2940, 2856, 1697, 1684, 1521, 1455, 1390, 1363, 1310, 1293, 1277, 1262, 1235, 1171, 1145, 1091, 1060, 1047, 1030, 1003, 901, 862, 777, 747, 730, 695.

HRMS (ESI-TOF): m/z calcd. for $C_{18}H_{25}NNaO_4$ ([M+Na]$^+$) 477.27238, found 477.27190.

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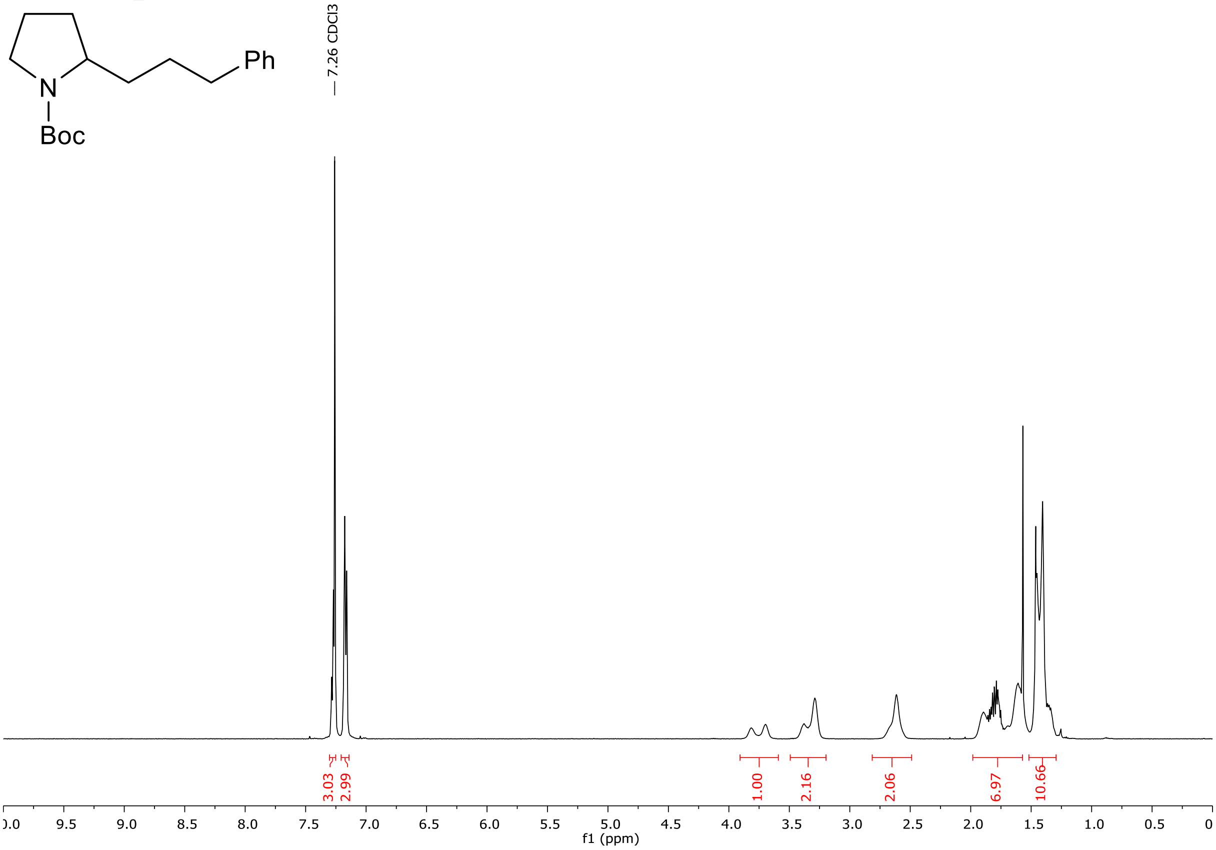
NMR spectra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9.0
8.5
8.0
7.5
7.0
6.5
6.0
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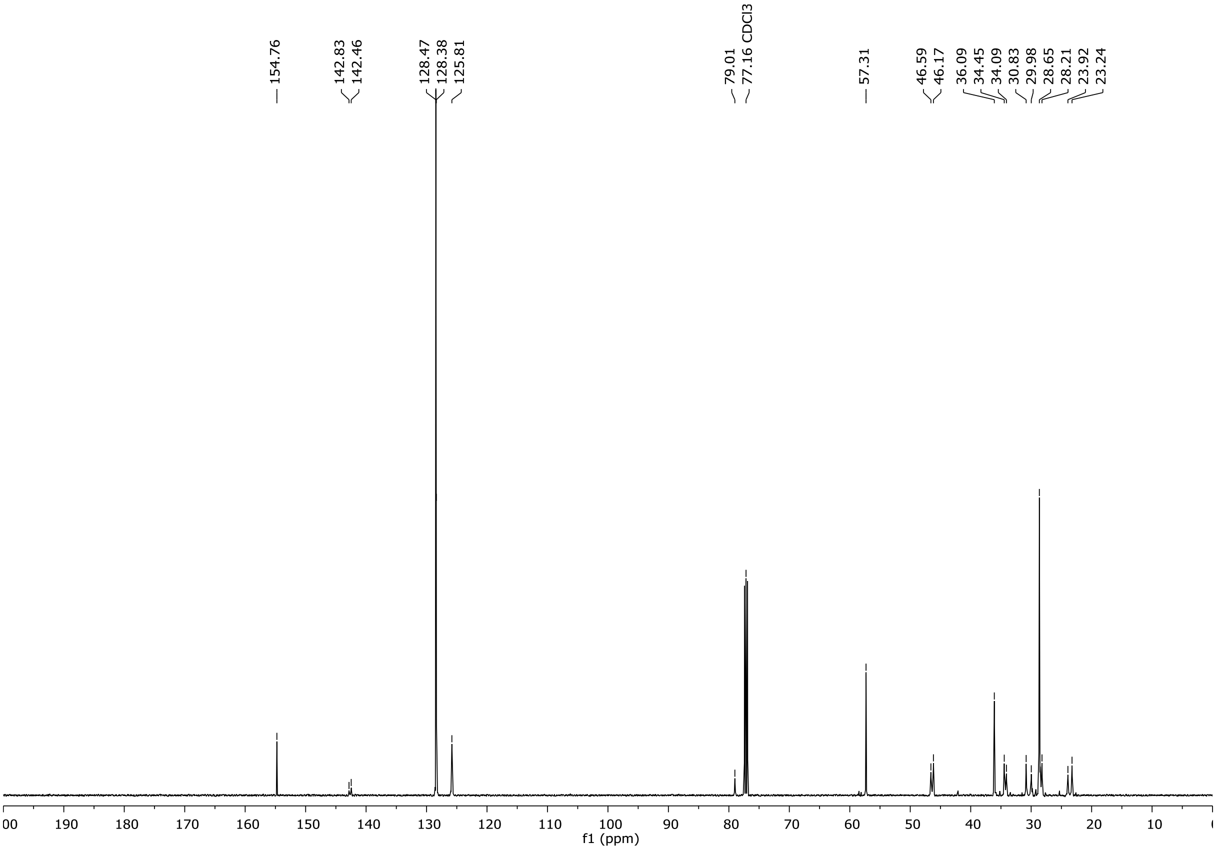
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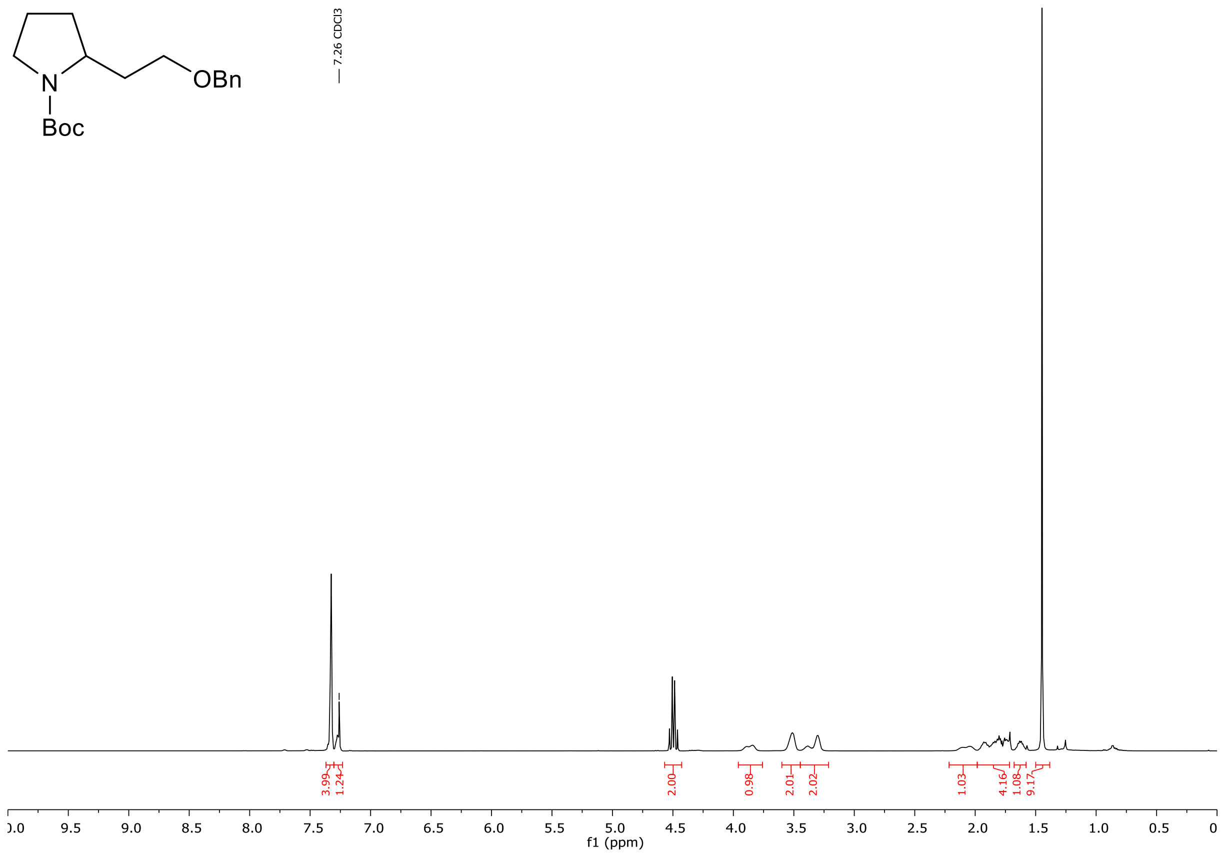
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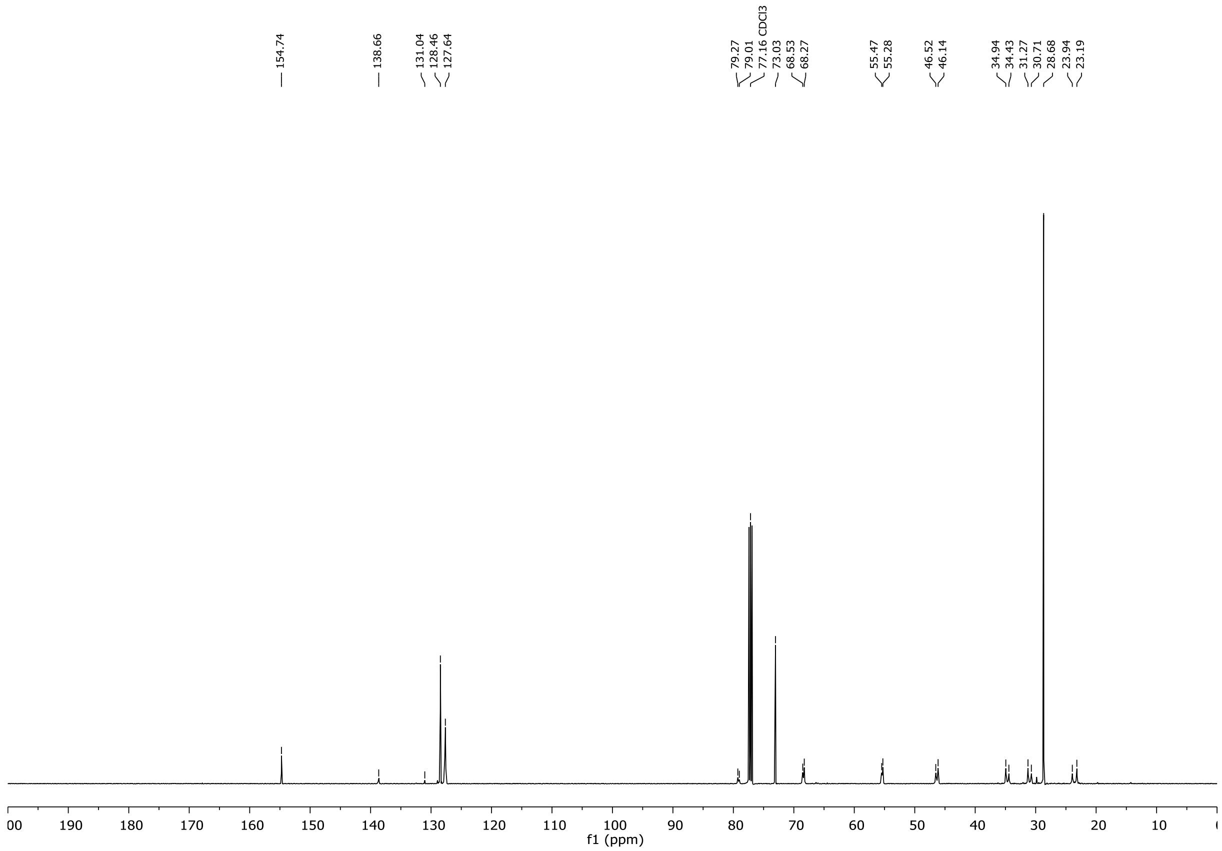
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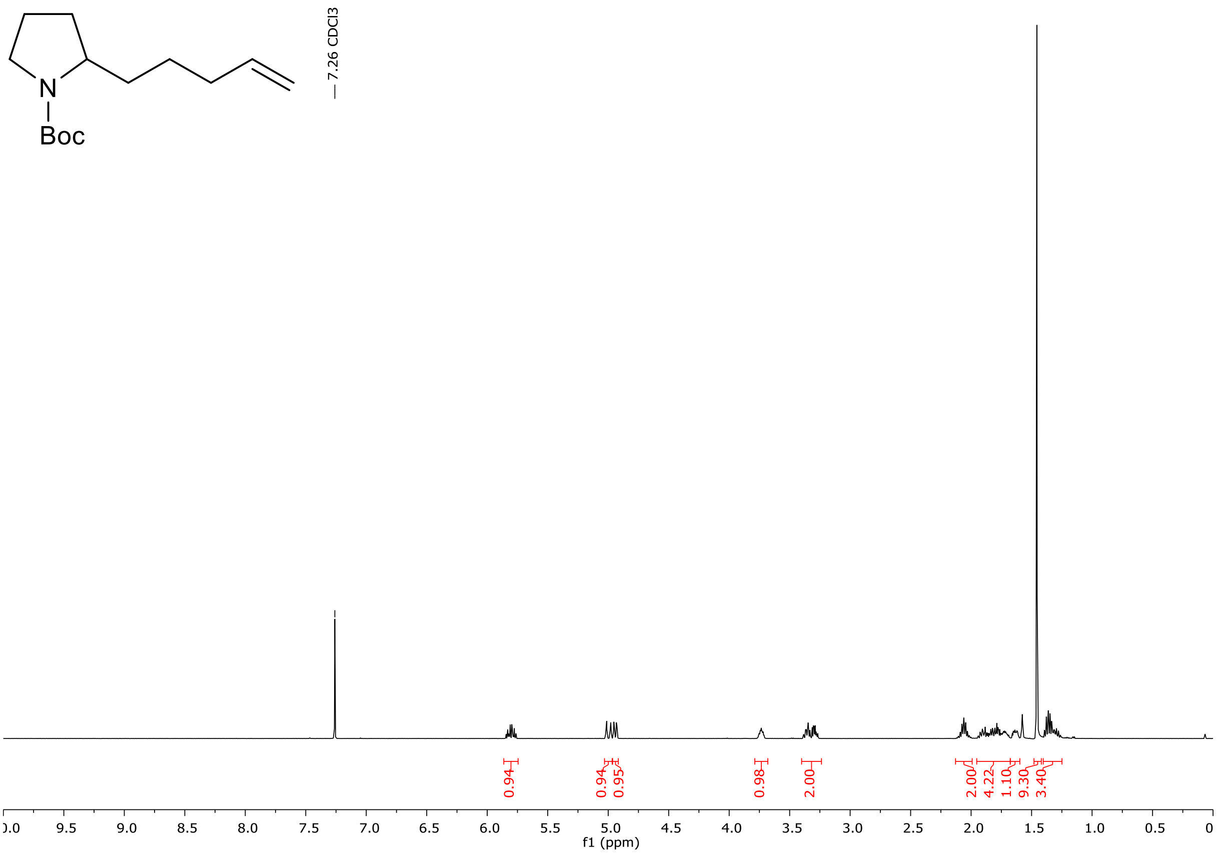
f1 (ppm)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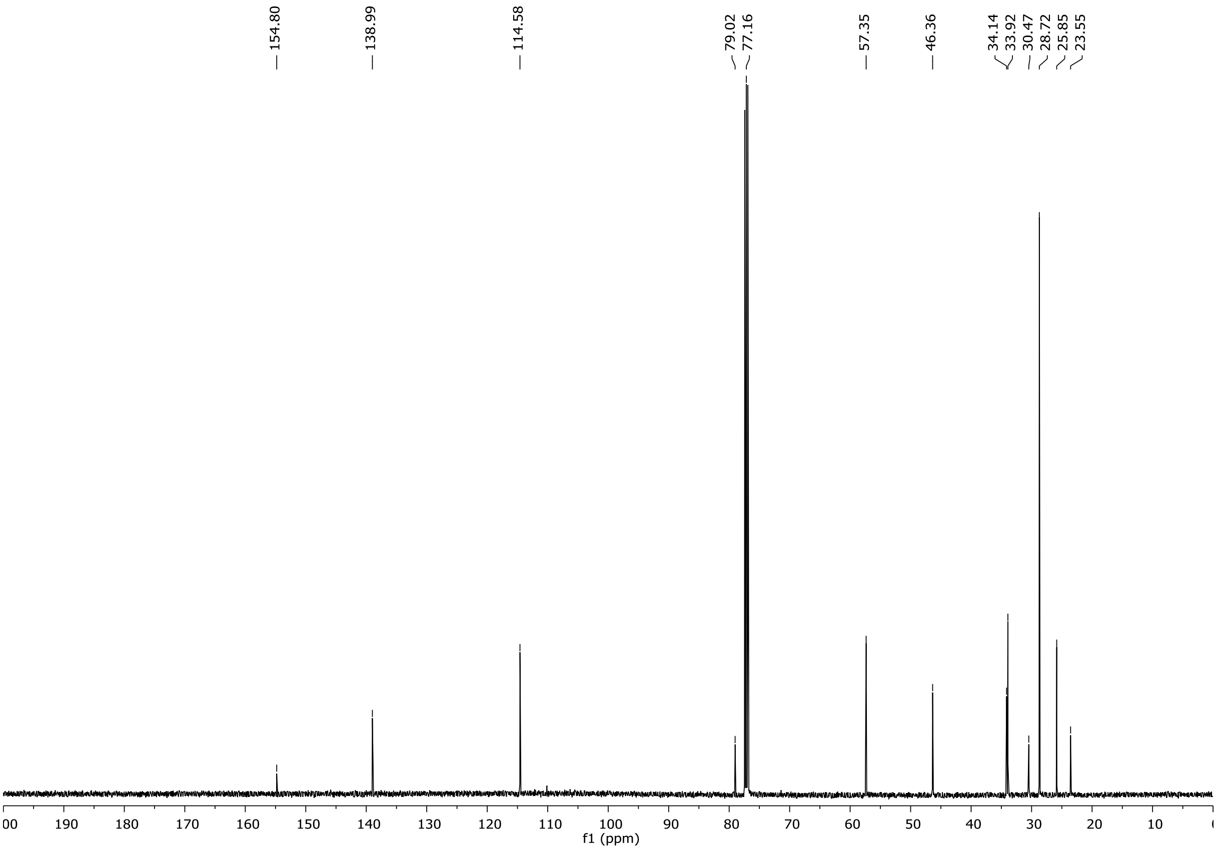
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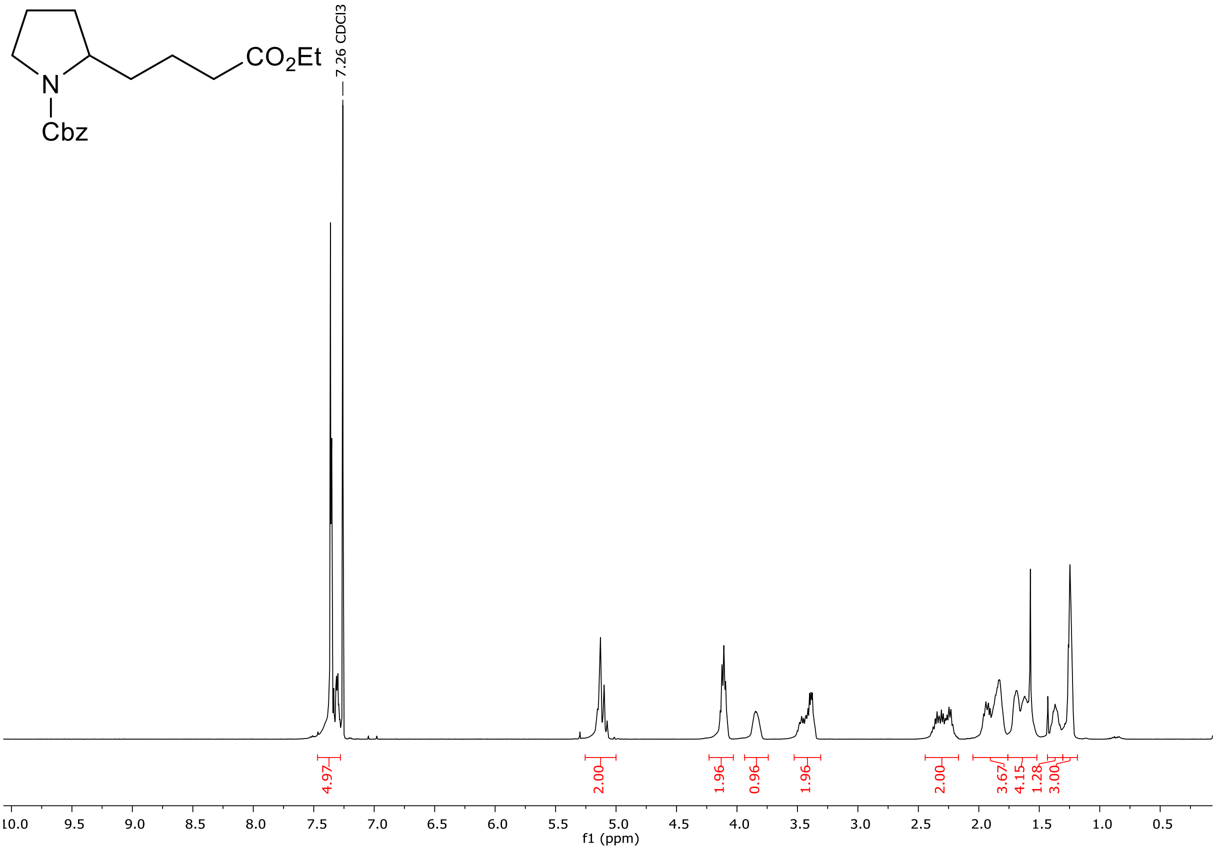
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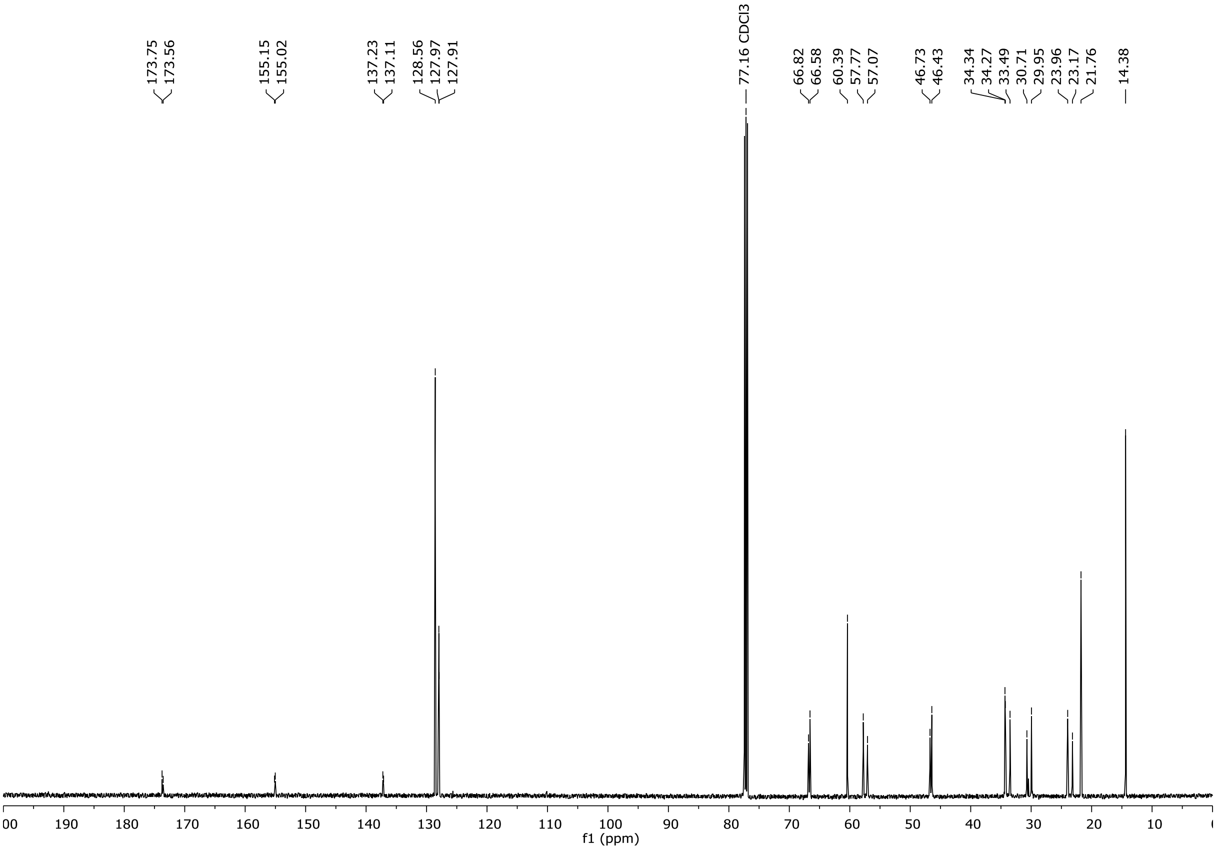
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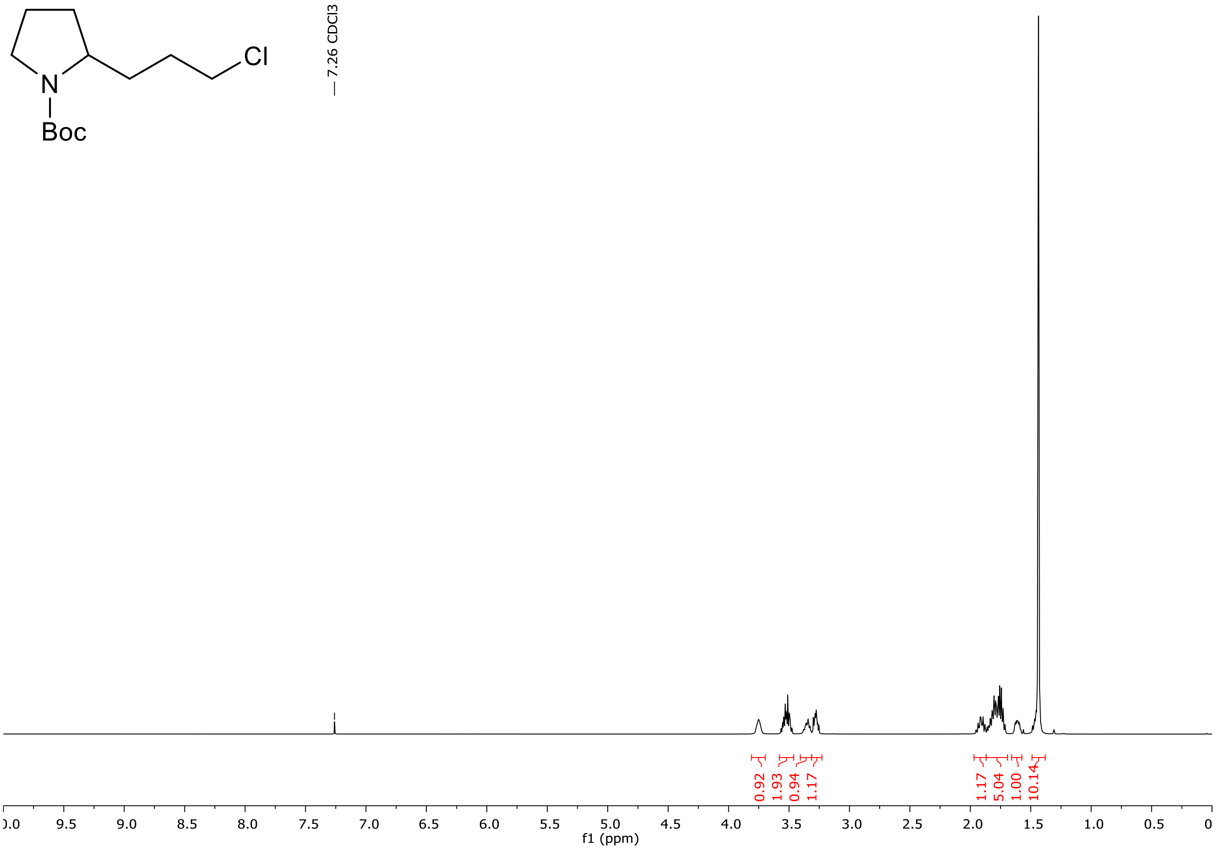
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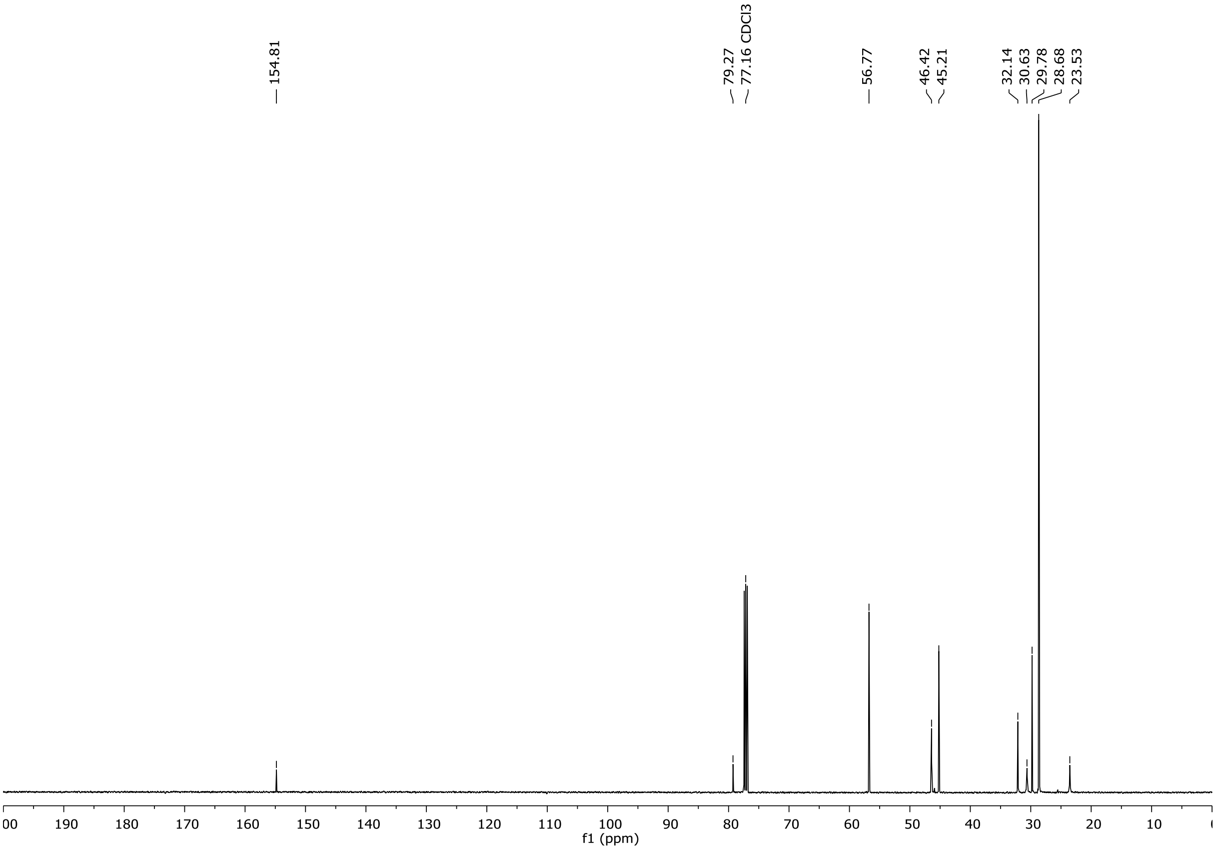
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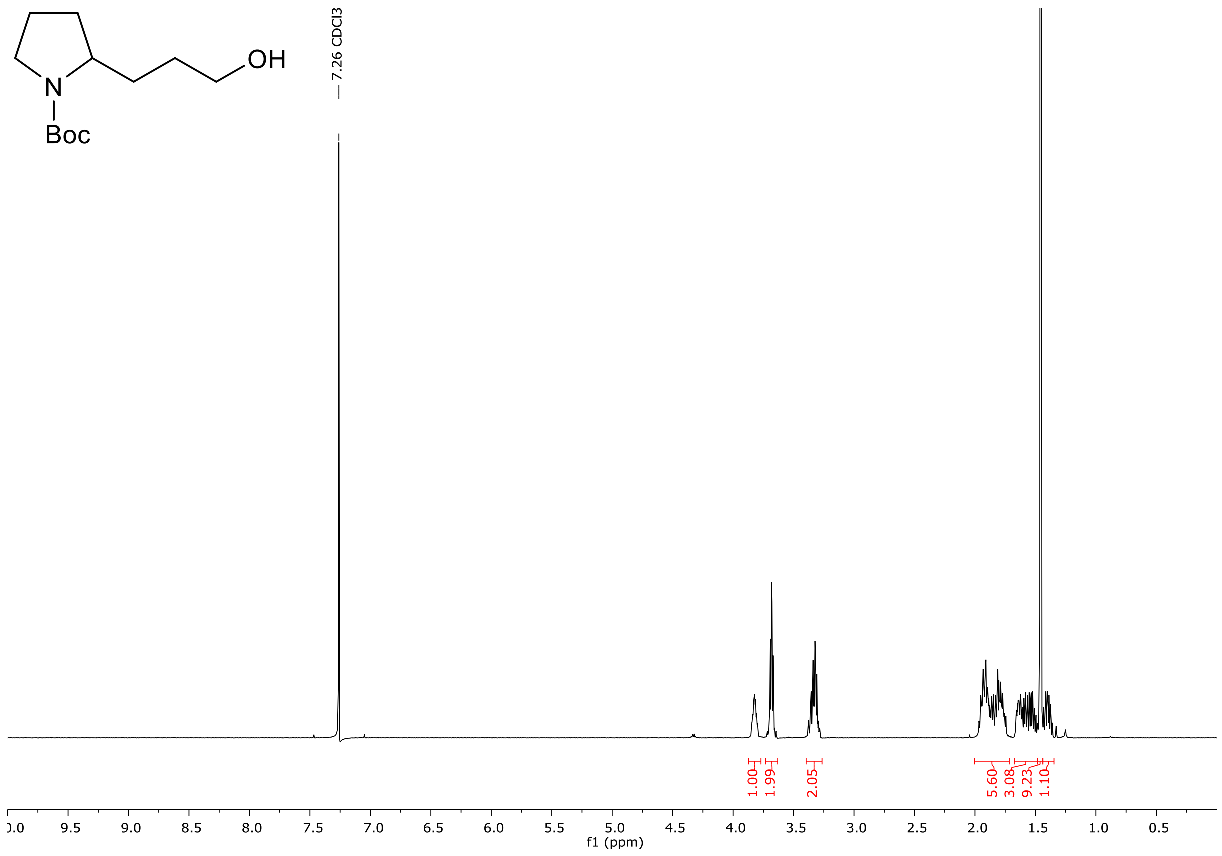

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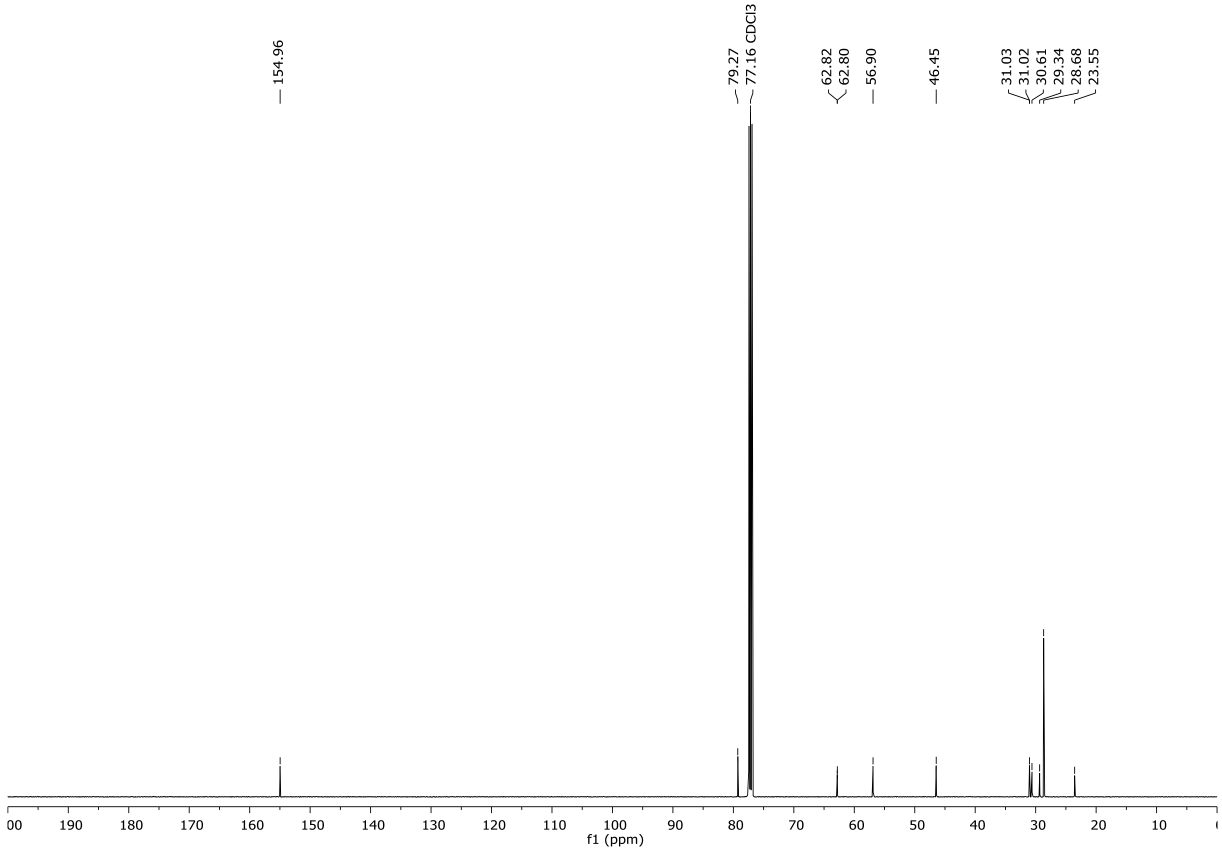

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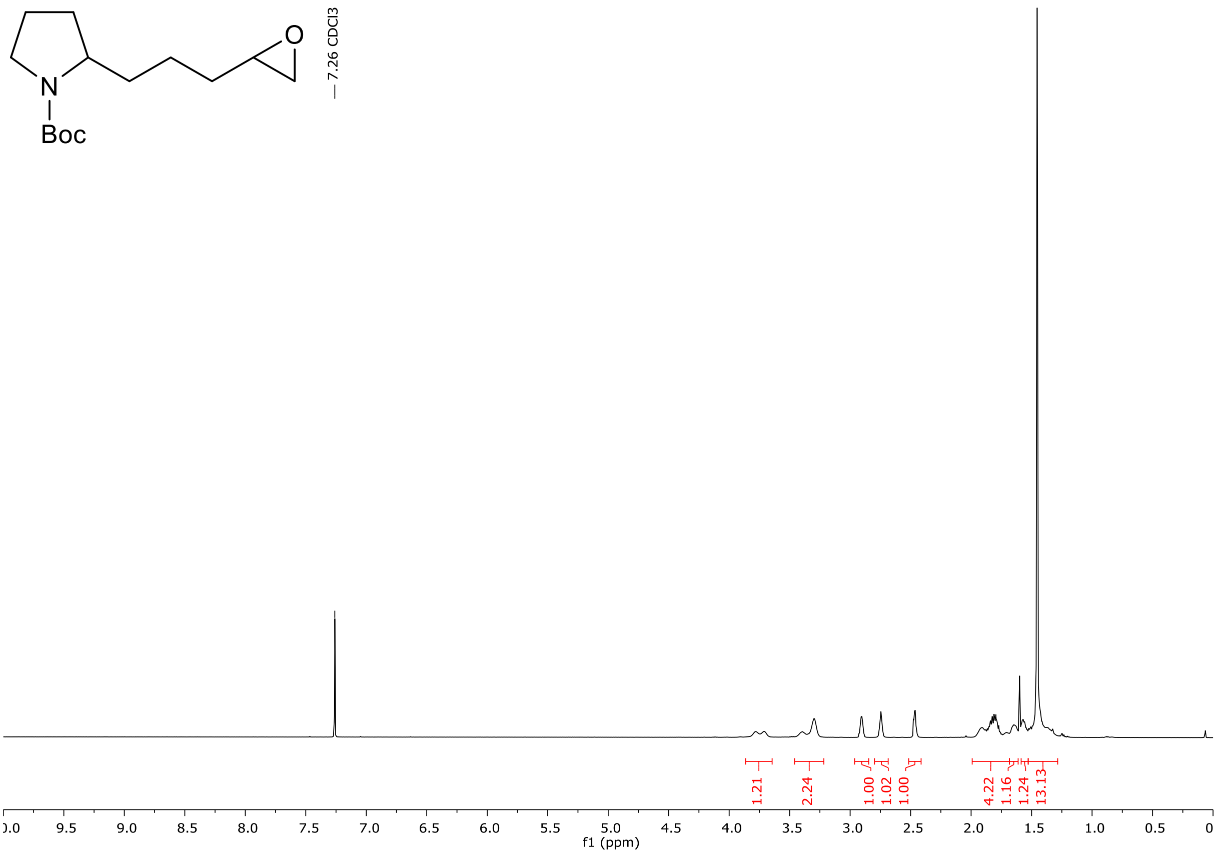
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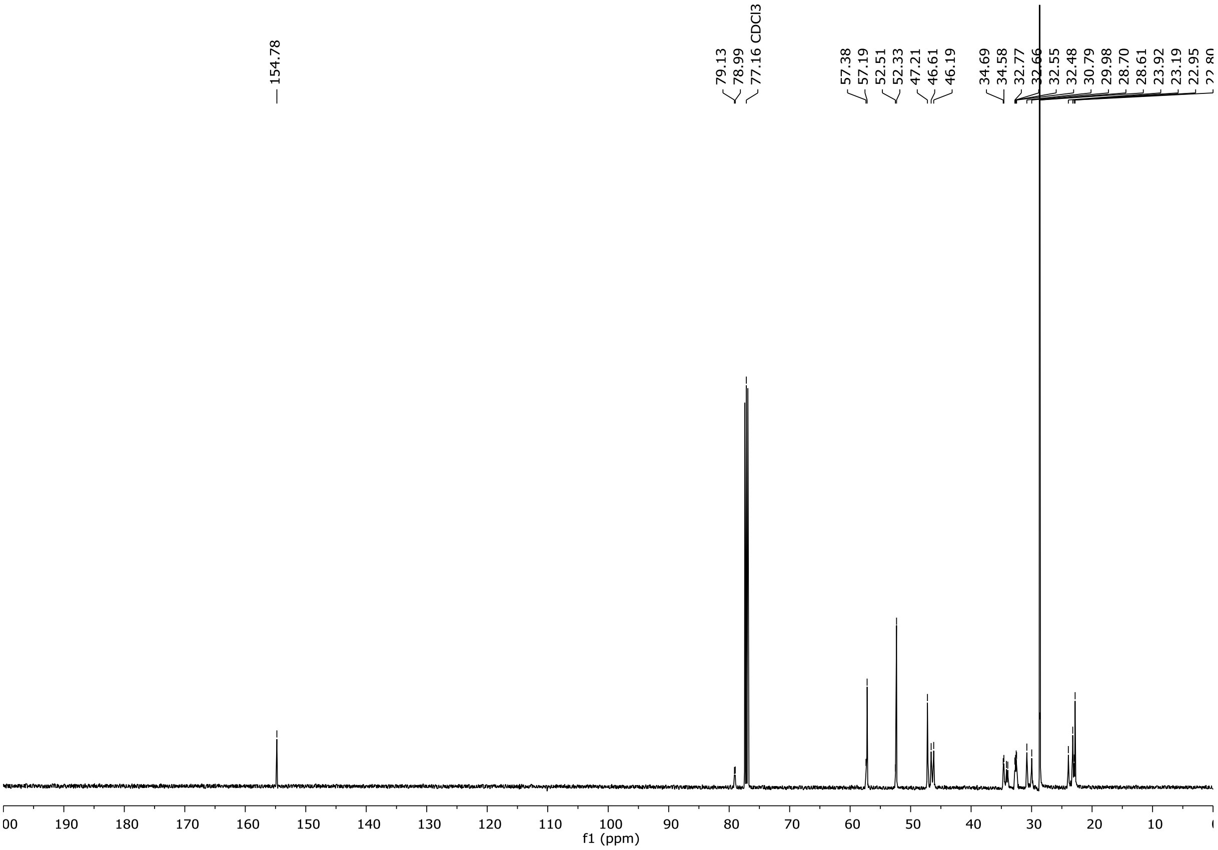
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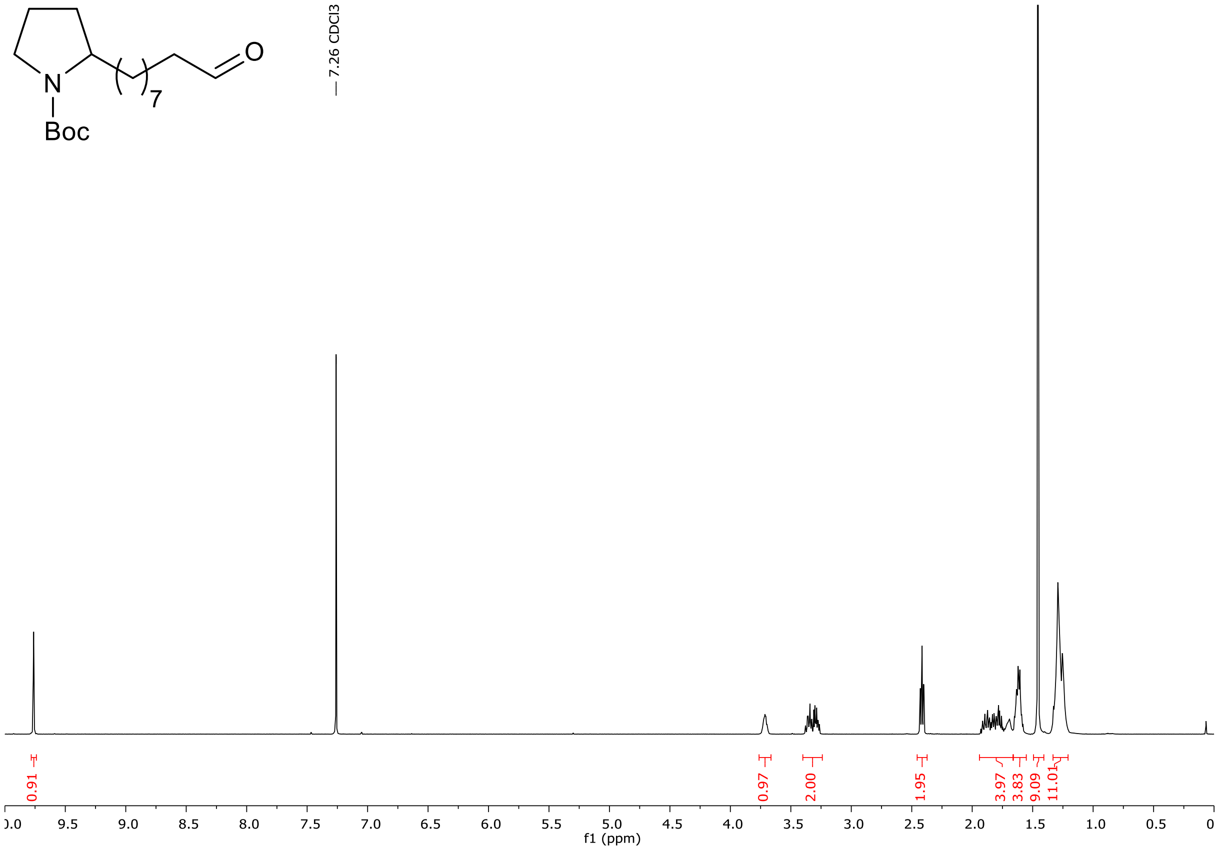
f1 (ppm)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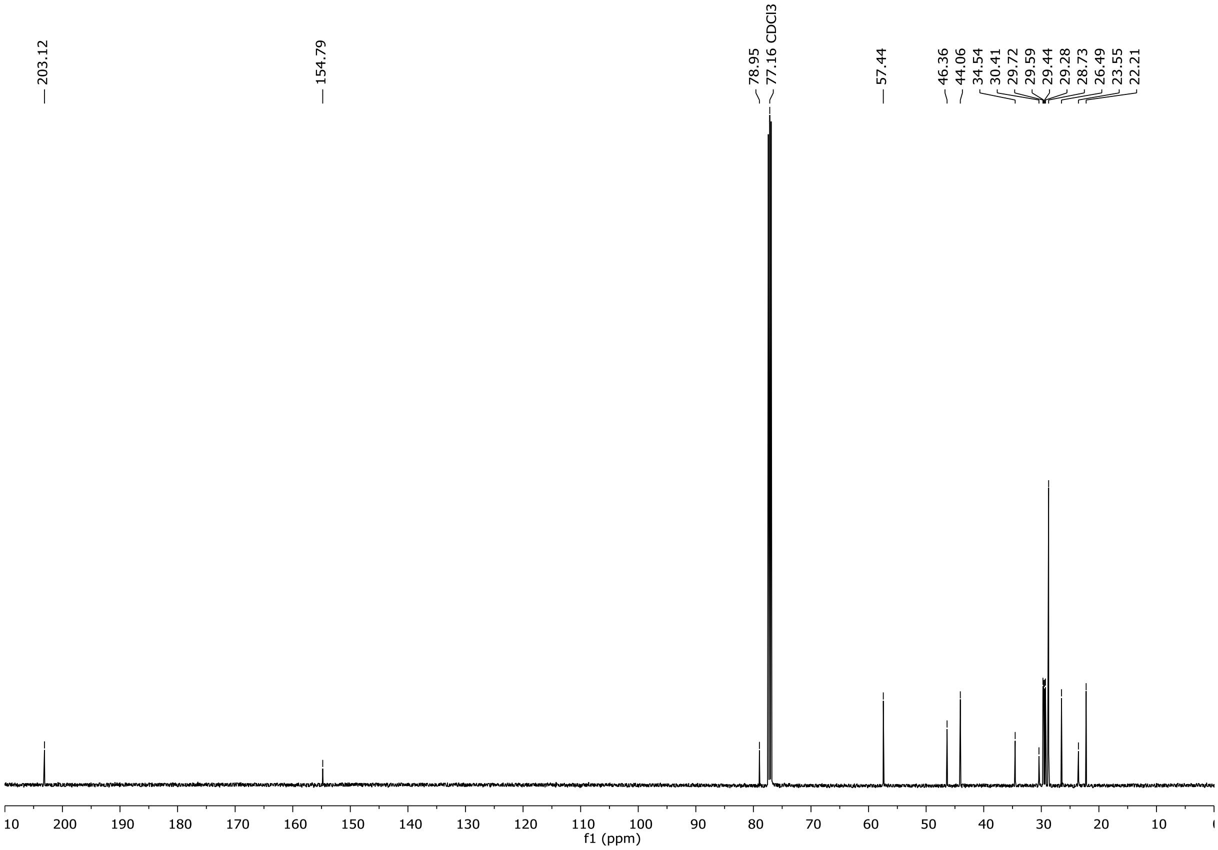
f1 (ppm)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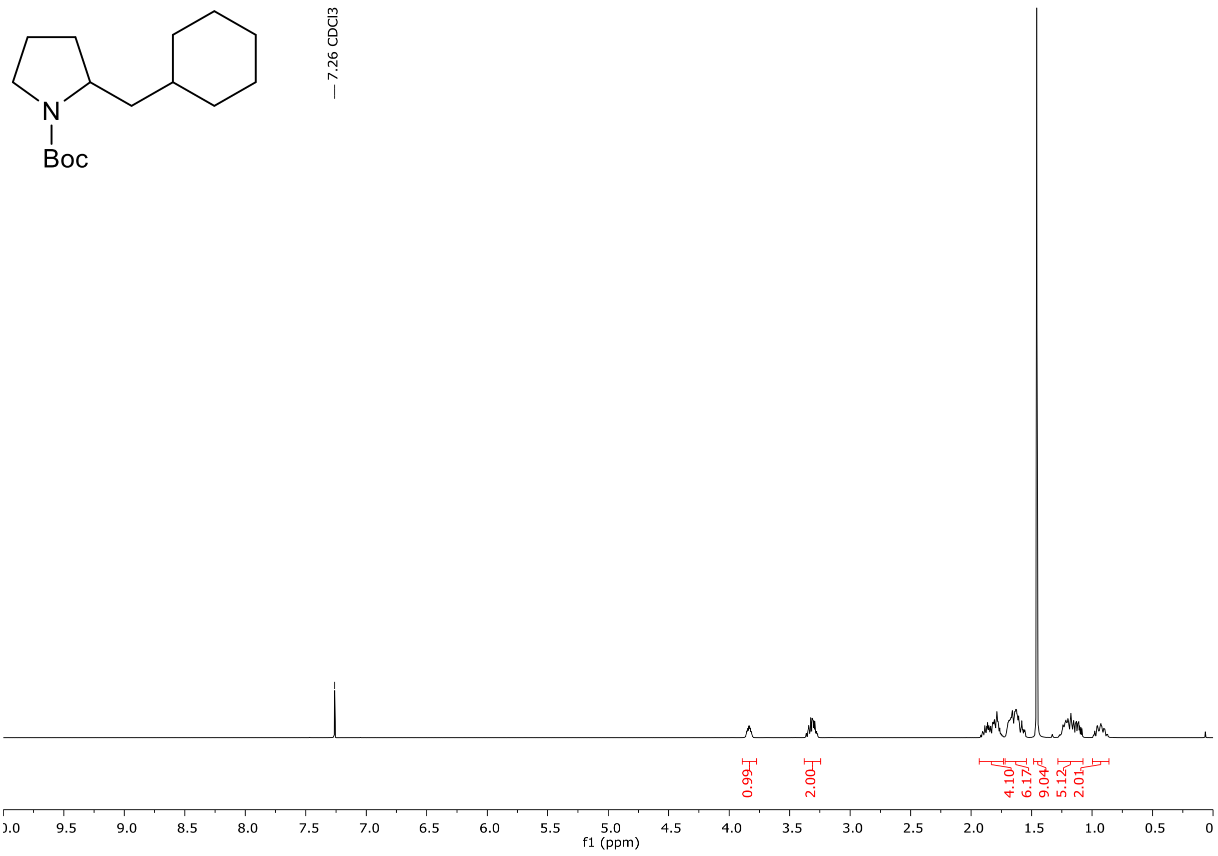
f1 (ppm)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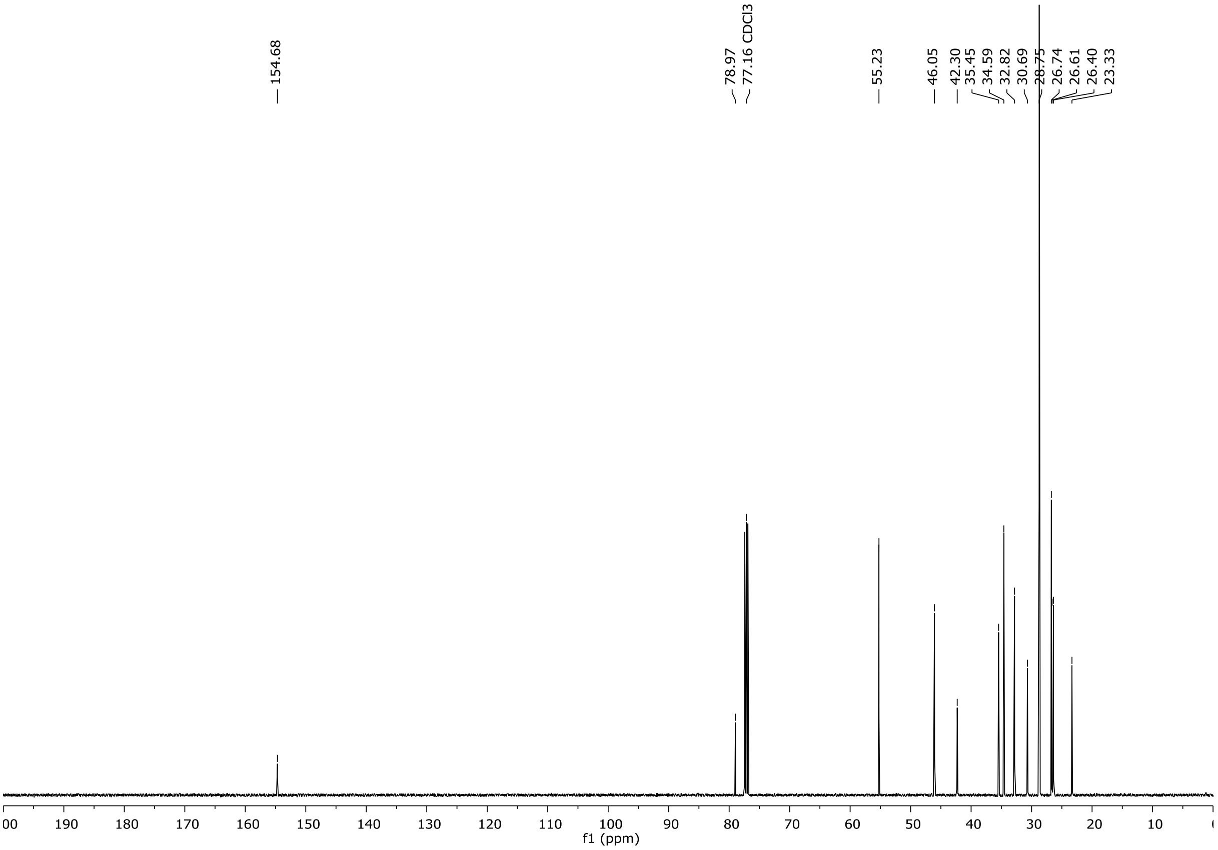
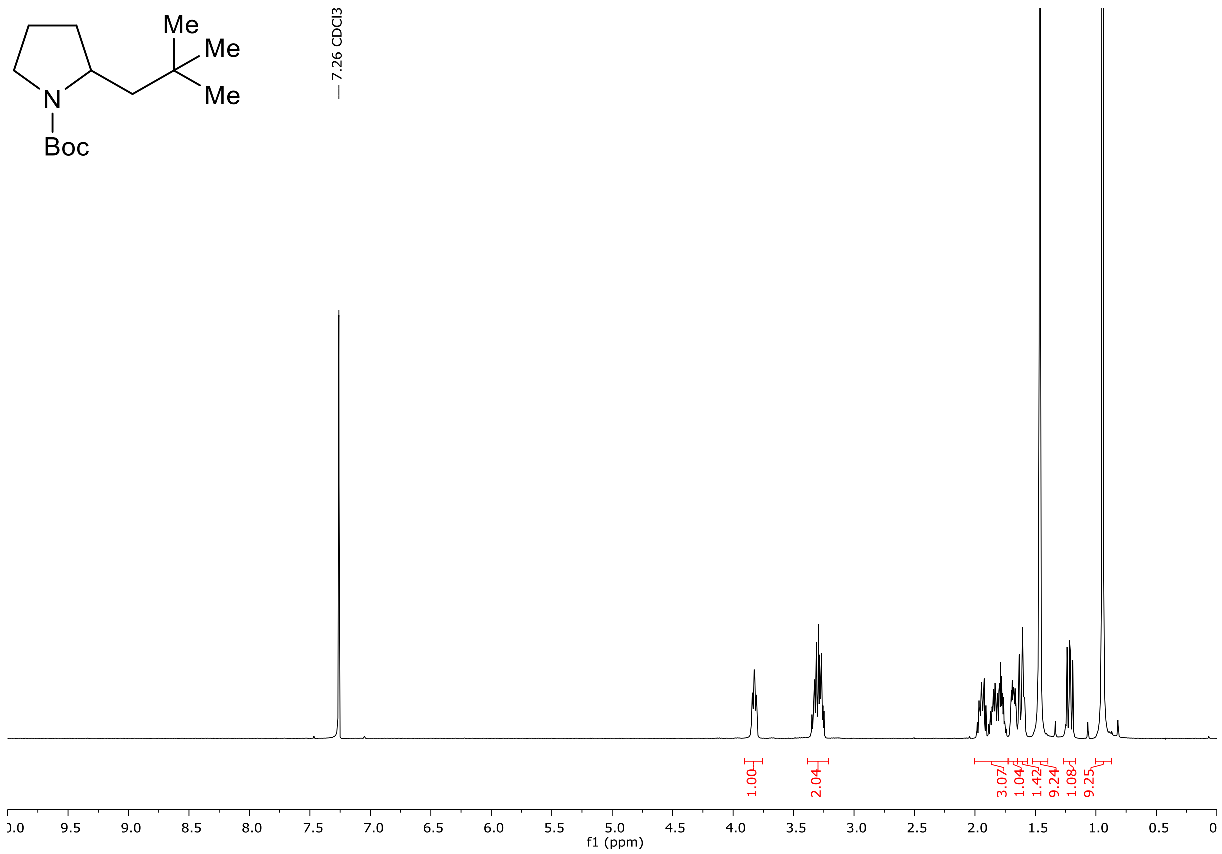
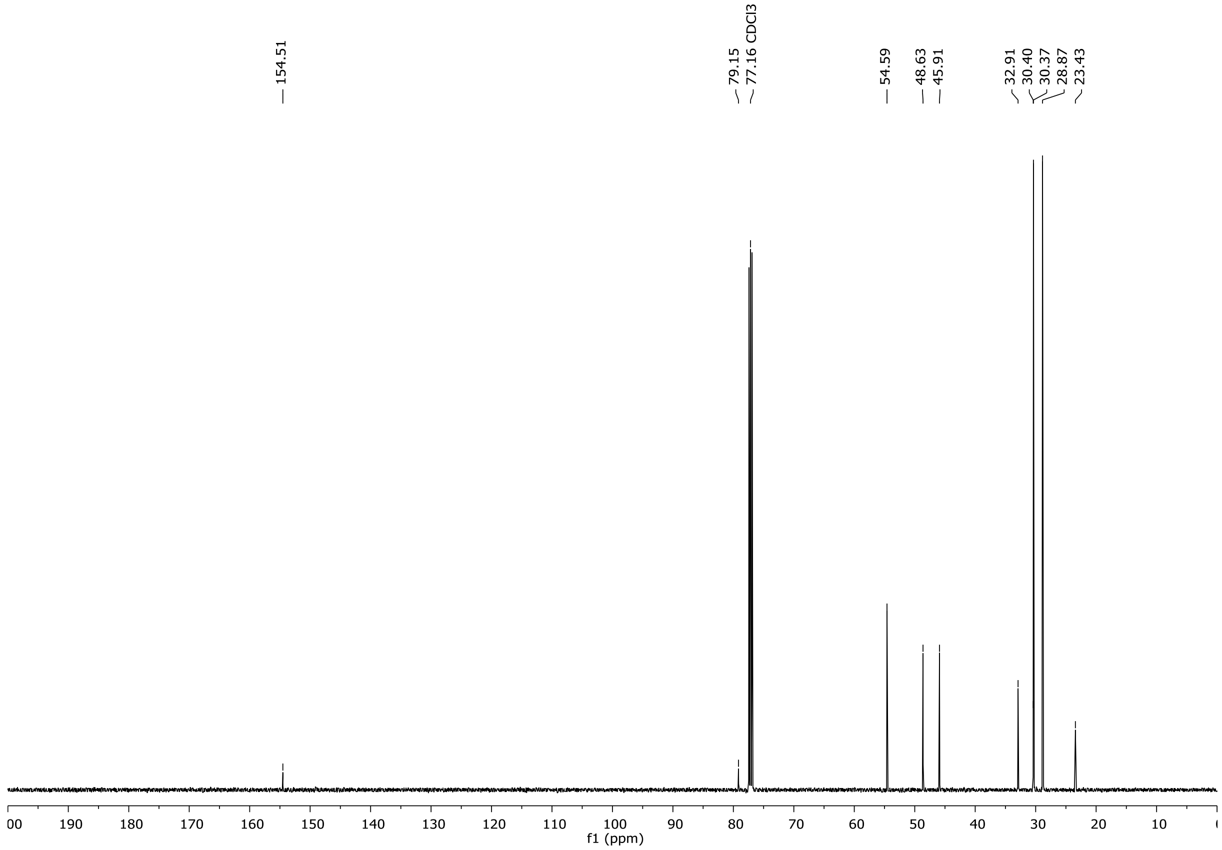
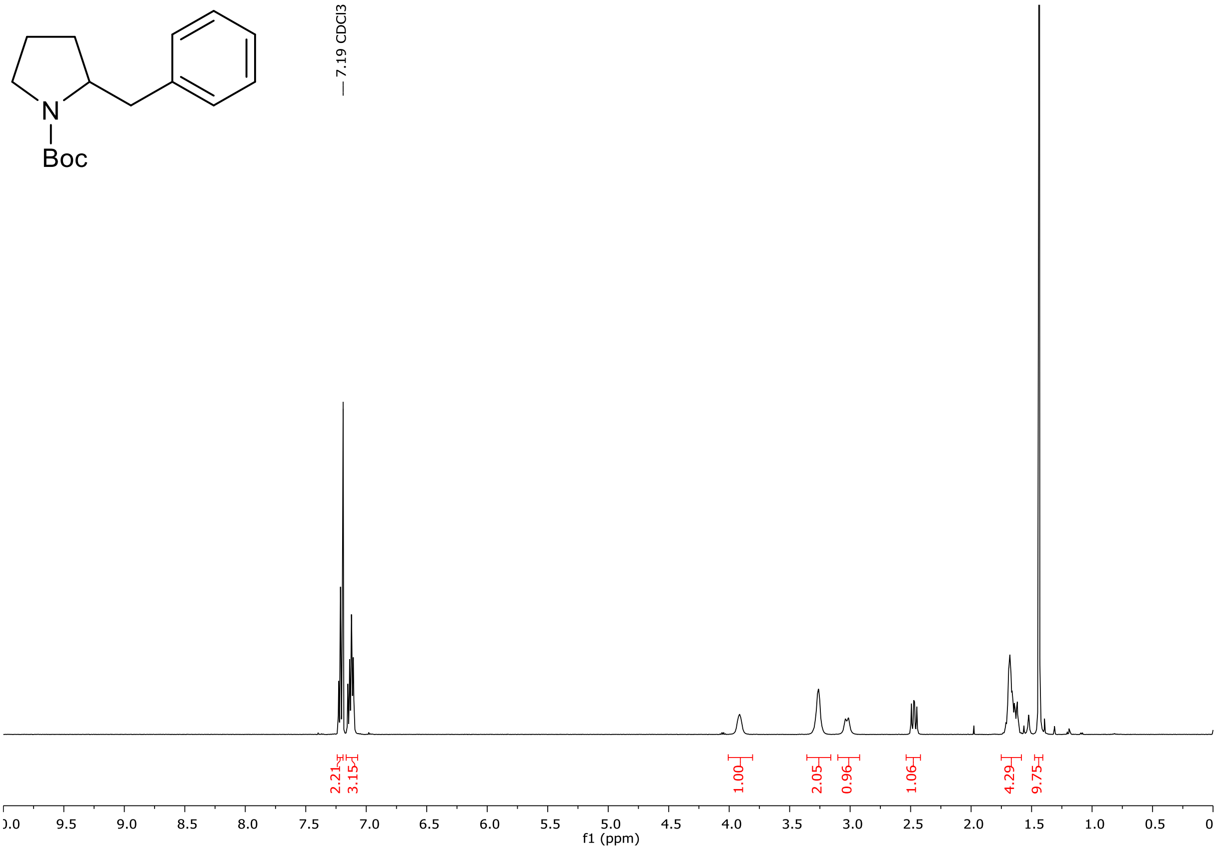
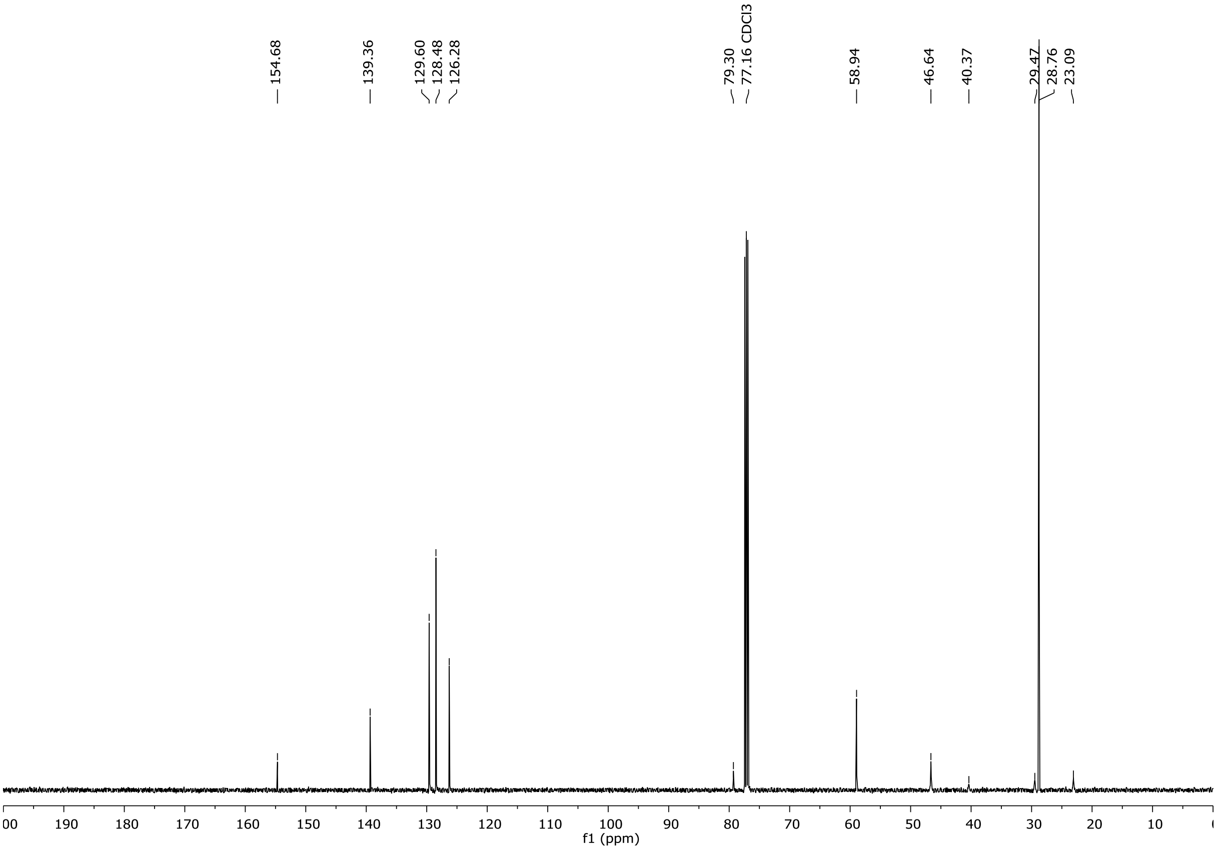
1.5
1.0
0.5
0
f1 (ppm)

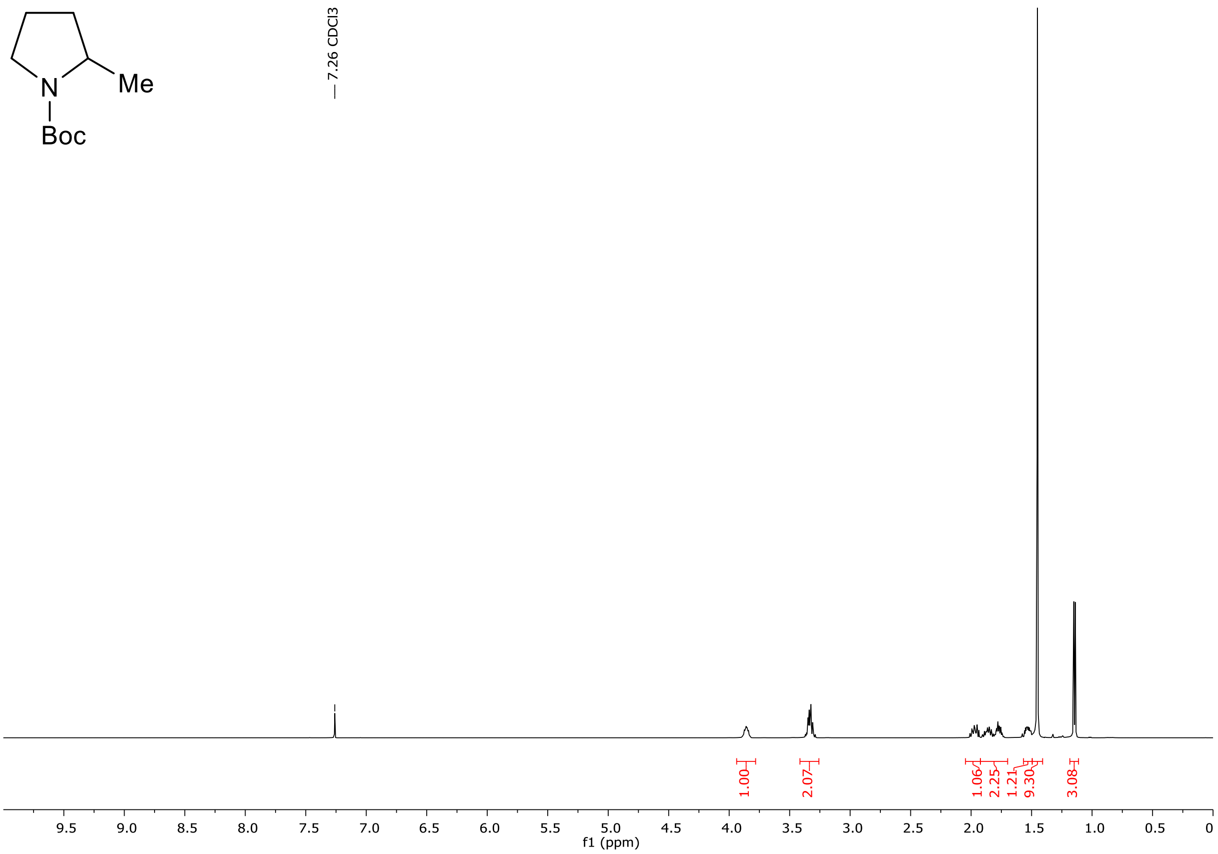

154.68
78.97
77.16 CDCl3
55.23
46.05
42.30
35.45
34.59
32.82
30.69
28.75
26.74
26.61
26.40
23.33
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

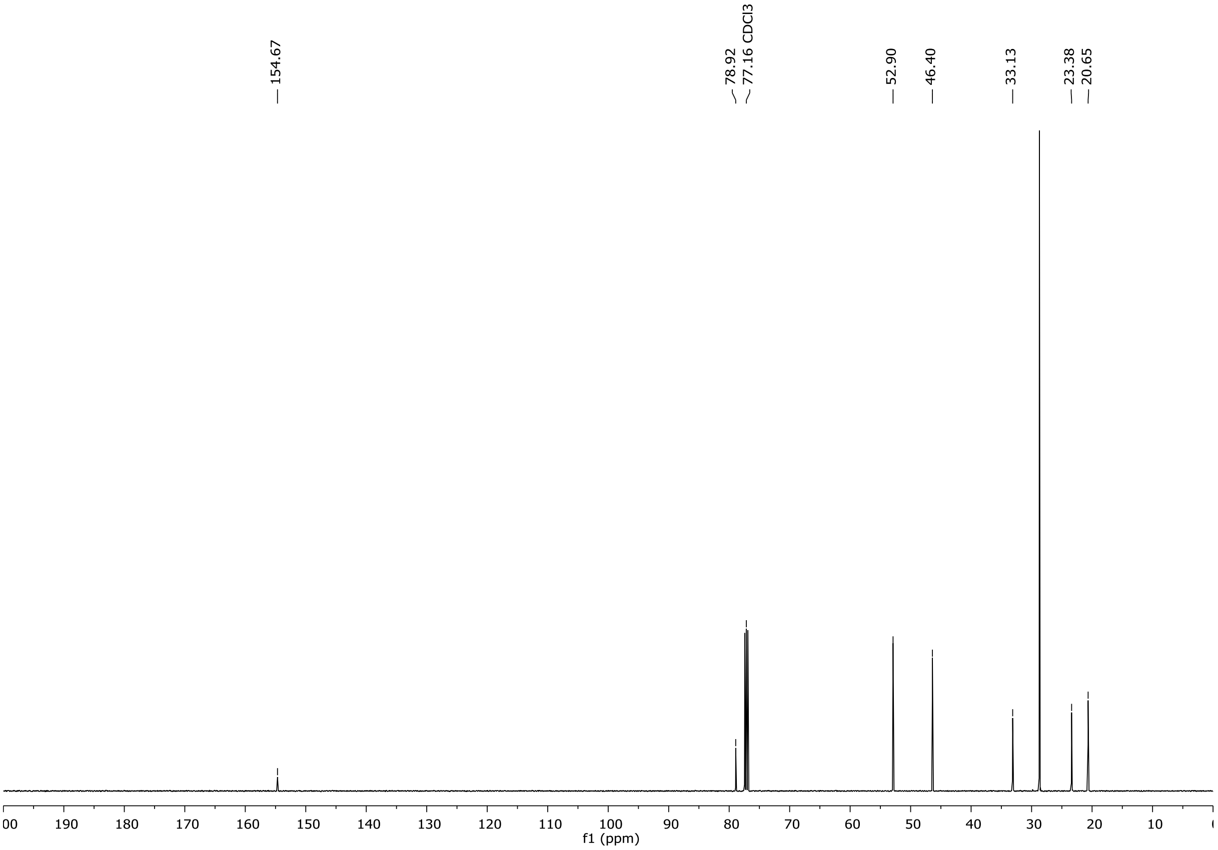

Me
Me
Me
N
Boc
7.26 CDCl3
1.00
2.04
3.07
1.04
1.42
9.24
1.08
9.25
).0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

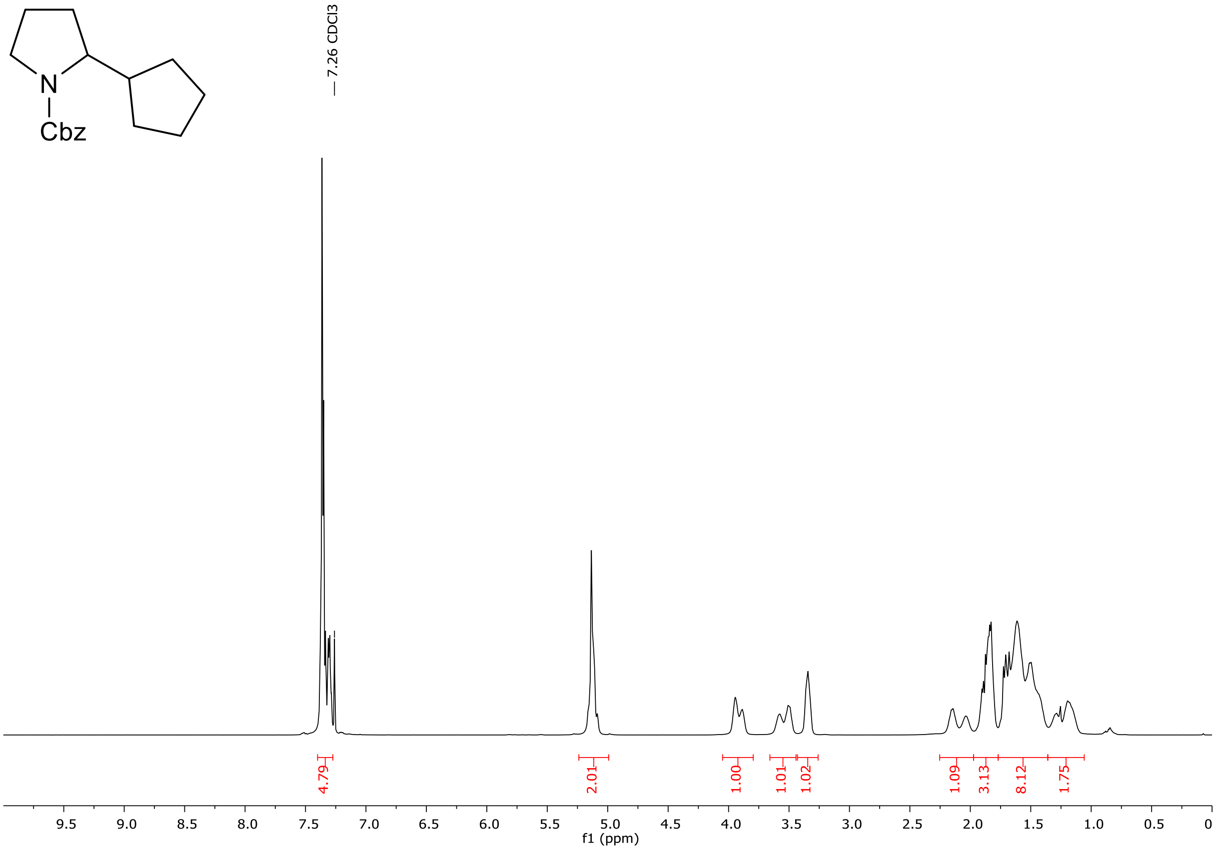

154.51
79.15
77.16 CDCl3
54.59
48.63
45.91
32.91
30.40
30.37
28.87
23.43
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

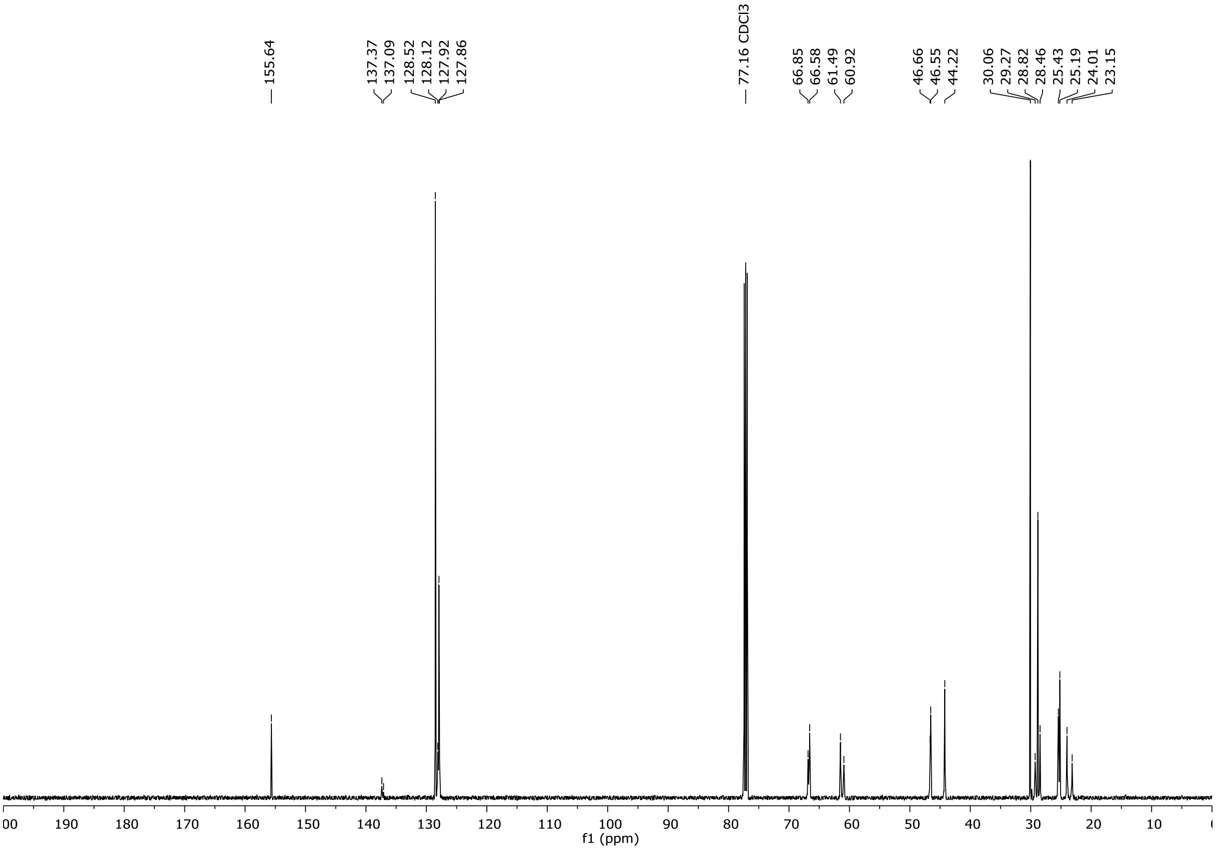

N
Boc
7.19 CDCl3
2.21
3.15
1.00
2.05
0.96
1.06
4.29
9.75
).0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

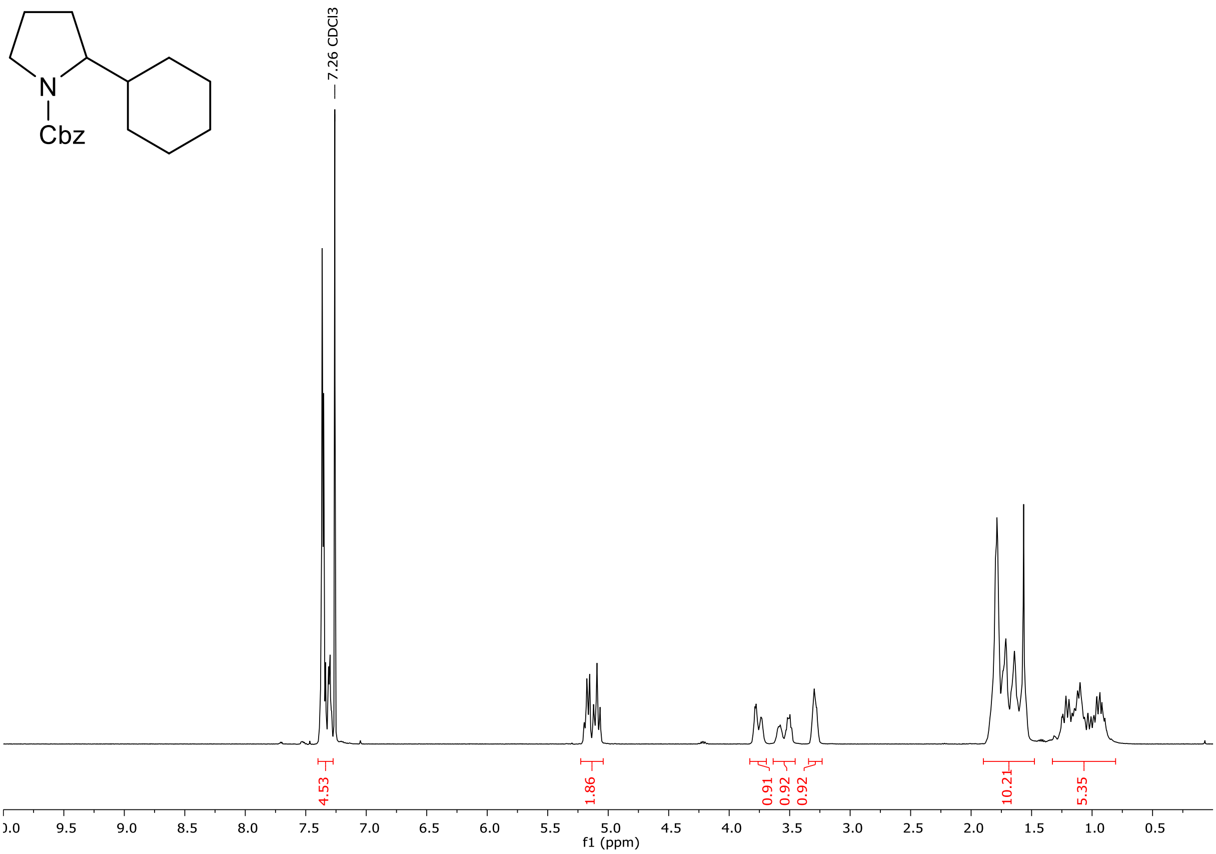

154.68
139.36
129.60
128.48
126.28
79.30
77.16 CDCl3
58.94
46.64
40.37
29.47
28.76
23.09
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

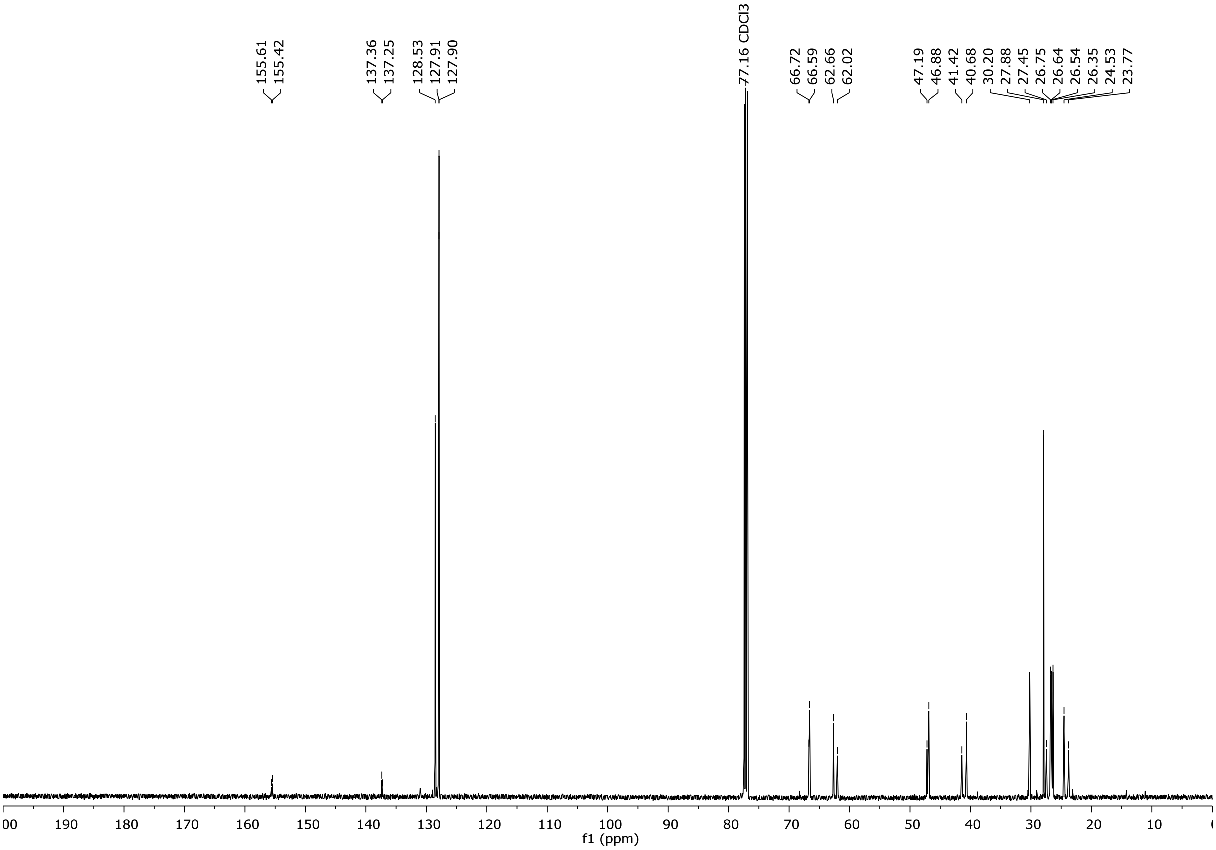

N
Me
Boc
7.26 CDCl3
1.00
2.07
1.06
2.25
1.21
9.30
3.08
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

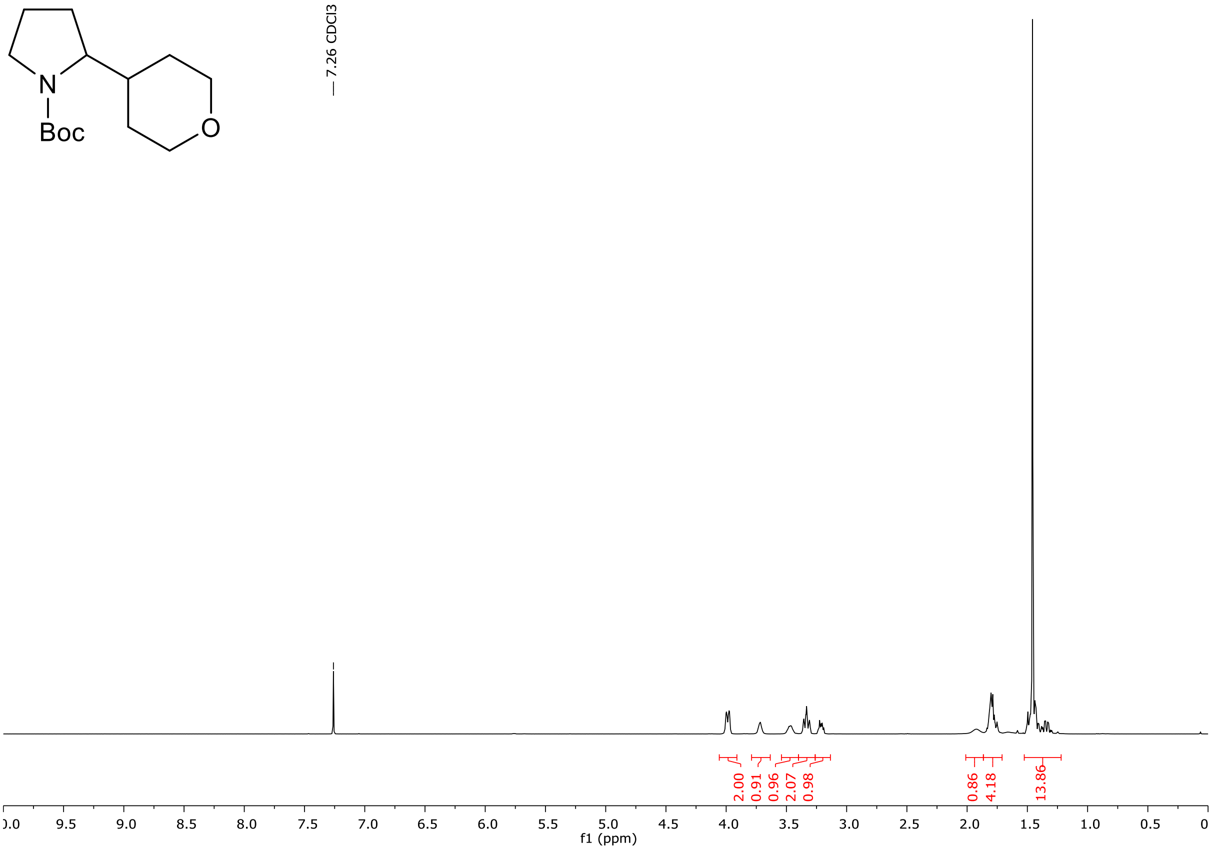

154.67
78.92
77.16 CDCl3
52.90
46.40
33.13
23.38
20.65
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

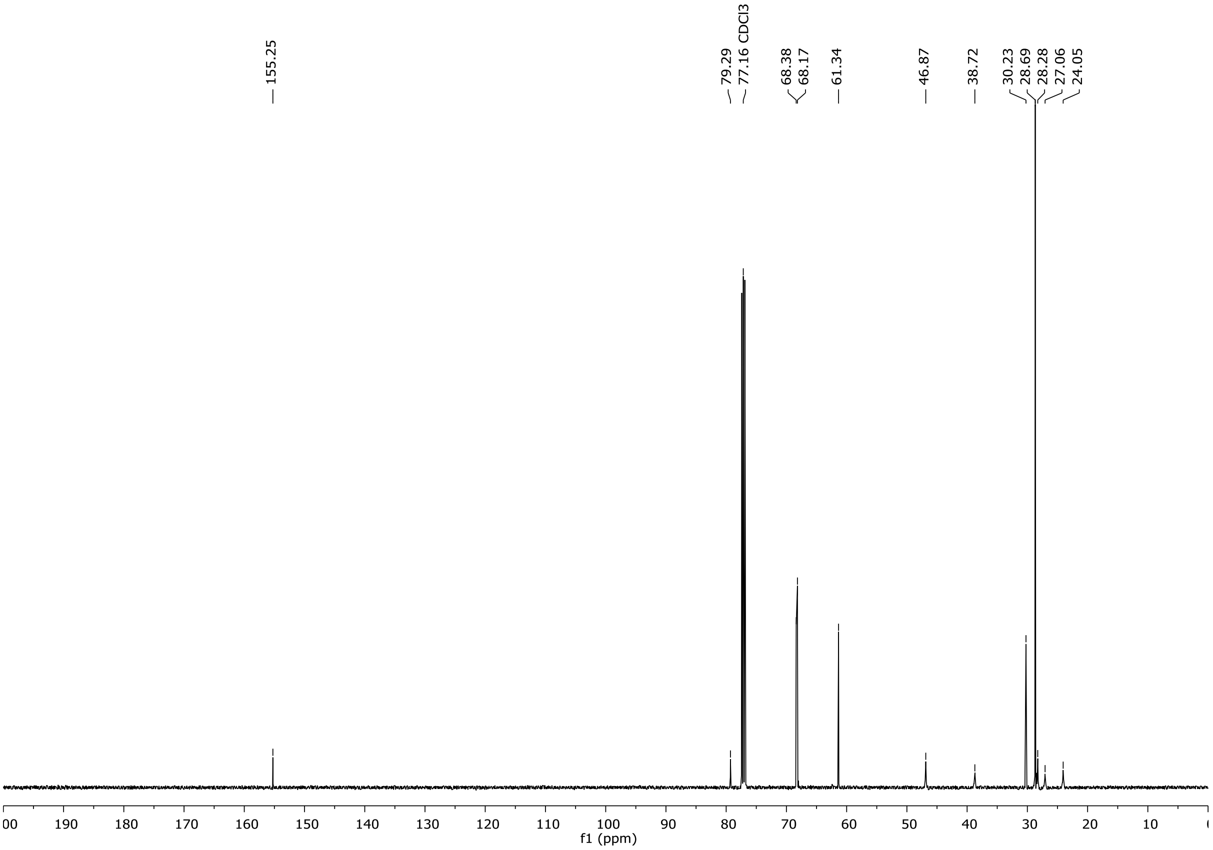

N
Cbz
7.26 CDCl3
4.79
2.01
1.00
1.01
1.02
1.09
3.13
8.12
1.75
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

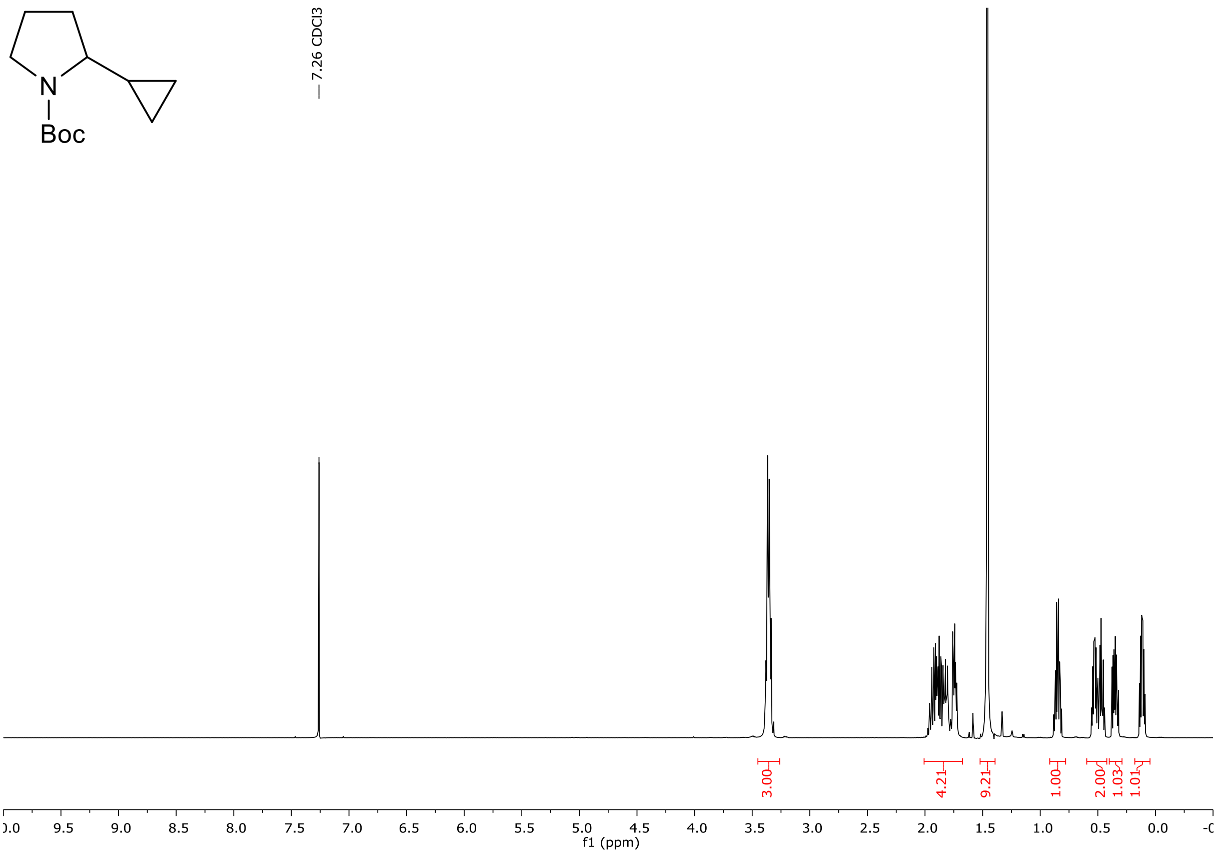

155.64
137.37
137.09
128.52
128.12
127.92
127.86
77.16 CDCl3
66.85
66.58
61.49
60.92
46.66
46.55
44.22
30.06
29.27
28.82
28.46
25.43
25.19
24.01
23.15
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

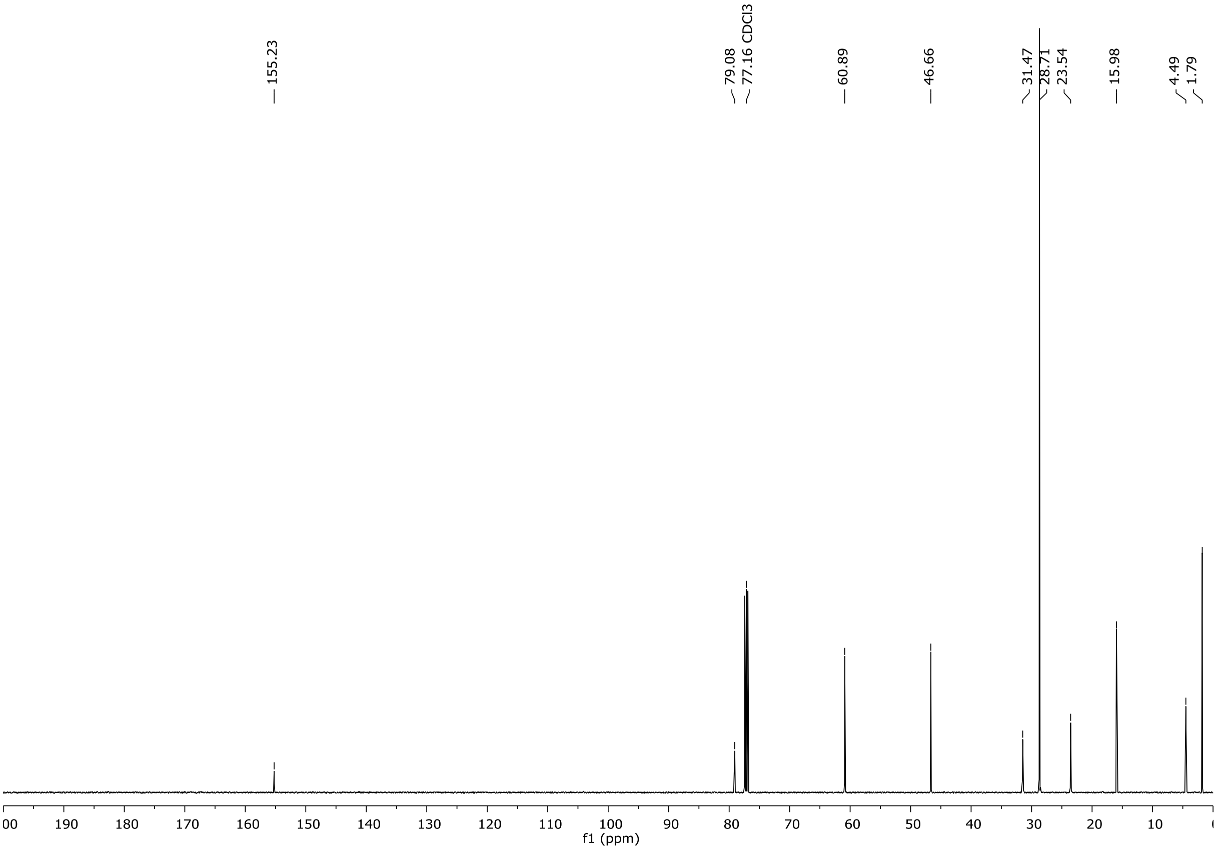

N
Cbz
7.26 CDCl3
4.53
1.86
0.91
0.92
0.92
10.21
5.35
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

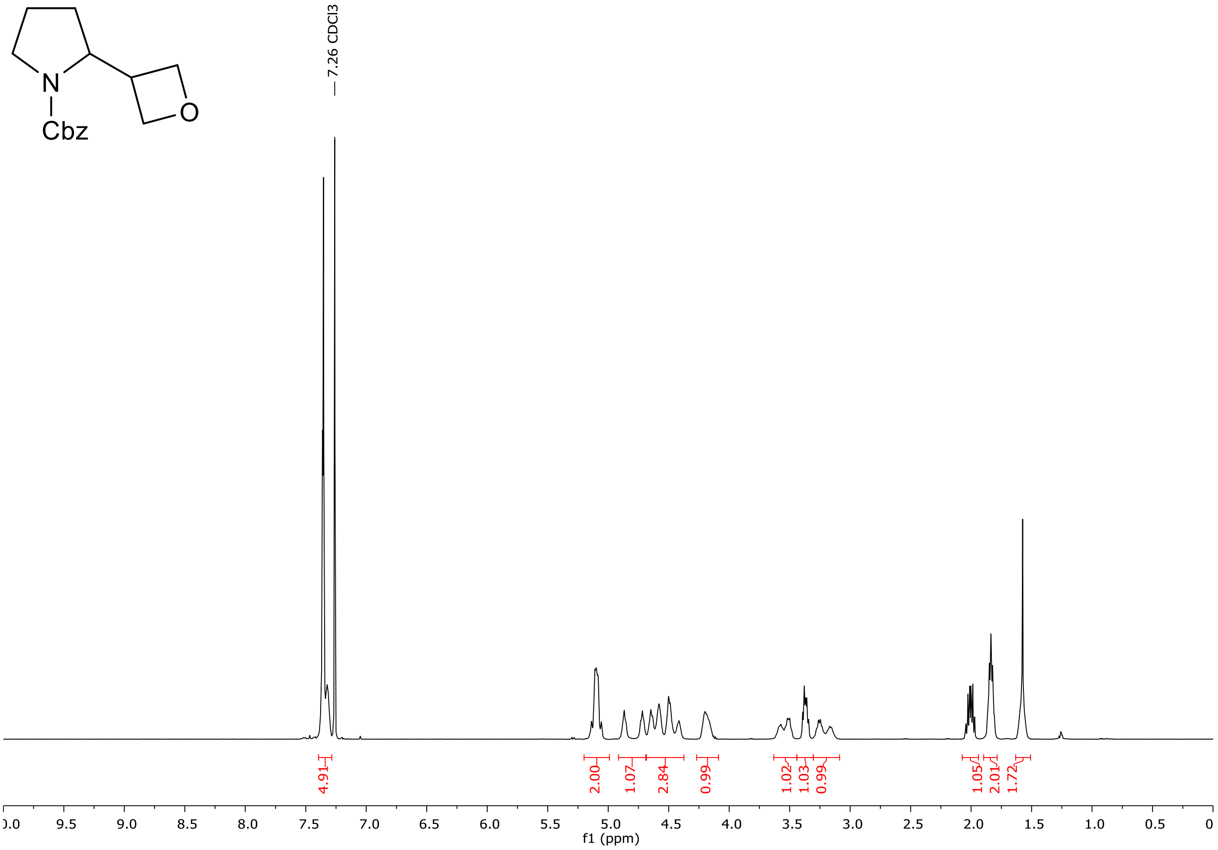

155.61
155.42
137.36
137.25
128.53
127.91
127.90
77.16 CDCl3
66.72
66.59
62.66
62.02
47.19
46.88
41.42
40.68
30.20
27.88
27.45
26.75
26.64
26.54
26.35
24.53
23.77
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

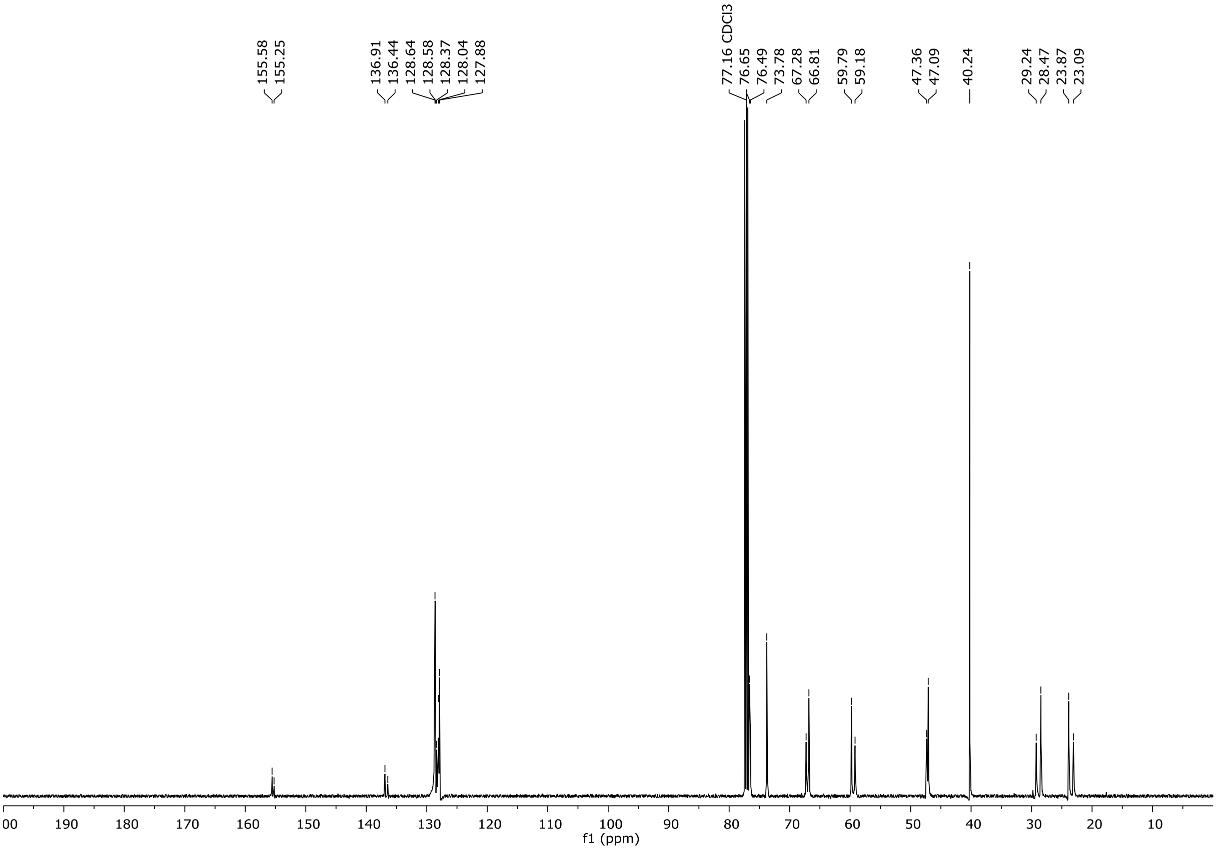

N
Boc
O
7.26 CDCl3
2.00
0.91
0.96
2.07
0.98
0.86
4.18
13.86
0.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

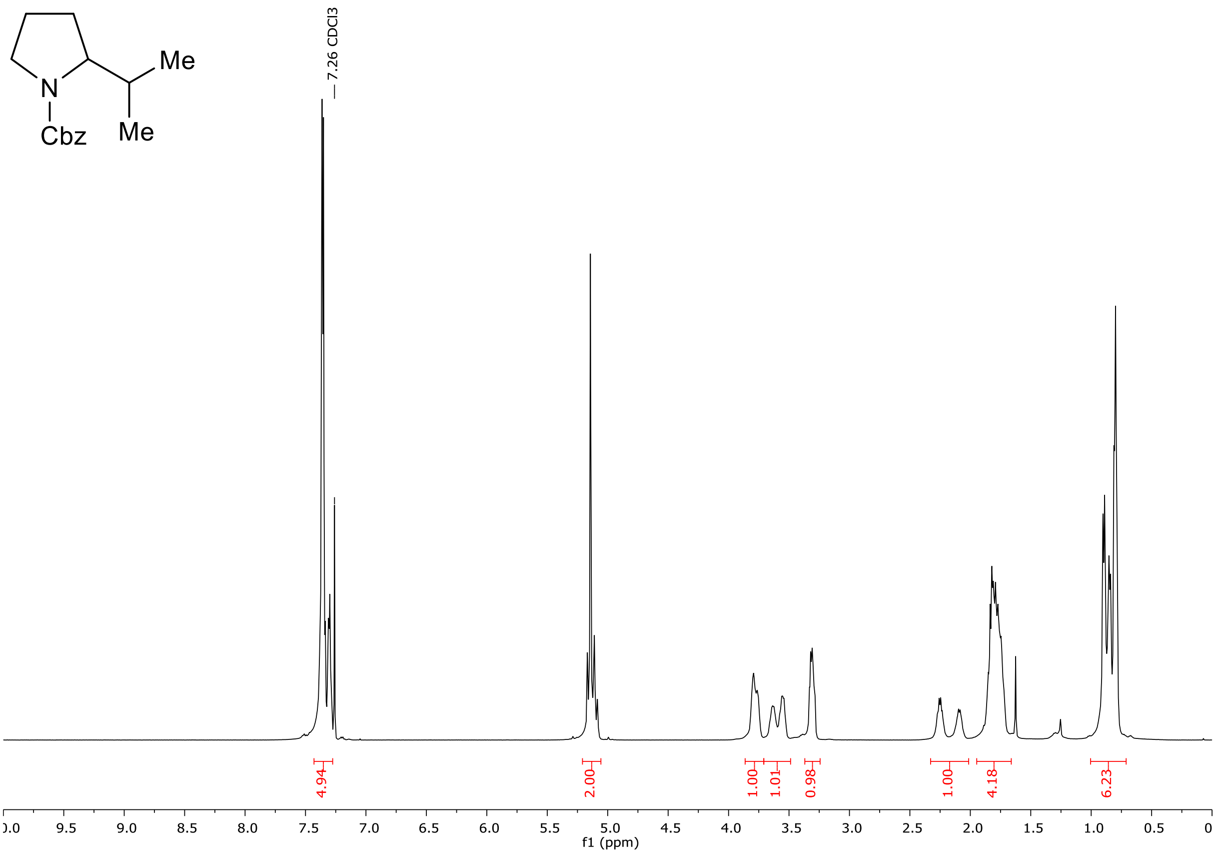

155.25
79.29
77.16 CDCl3
68.38
68.17
61.34
46.87
38.72
30.23
28.69
28.28
27.06
24.05
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

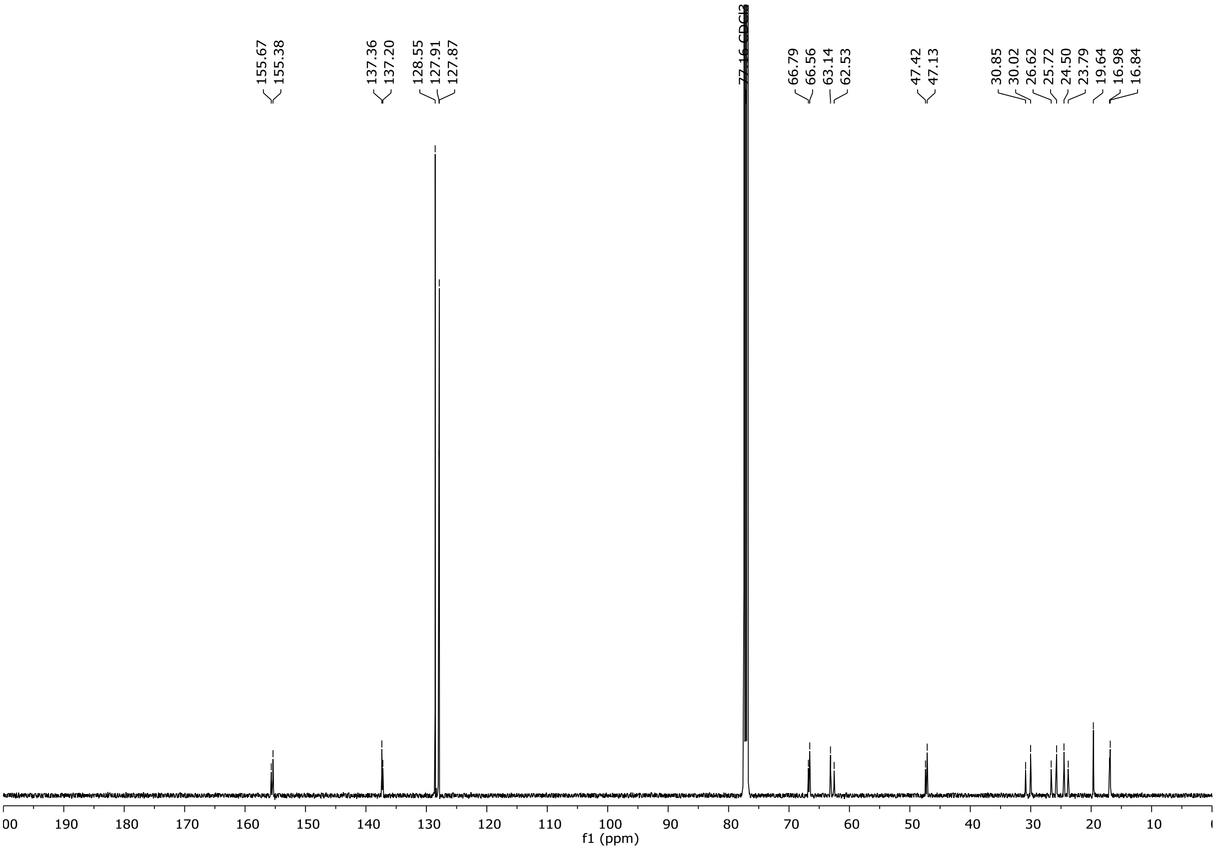

N
Boc
7.26 CDCl3
3.00
4.21
9.21
1.00
2.00
1.03
1.01
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

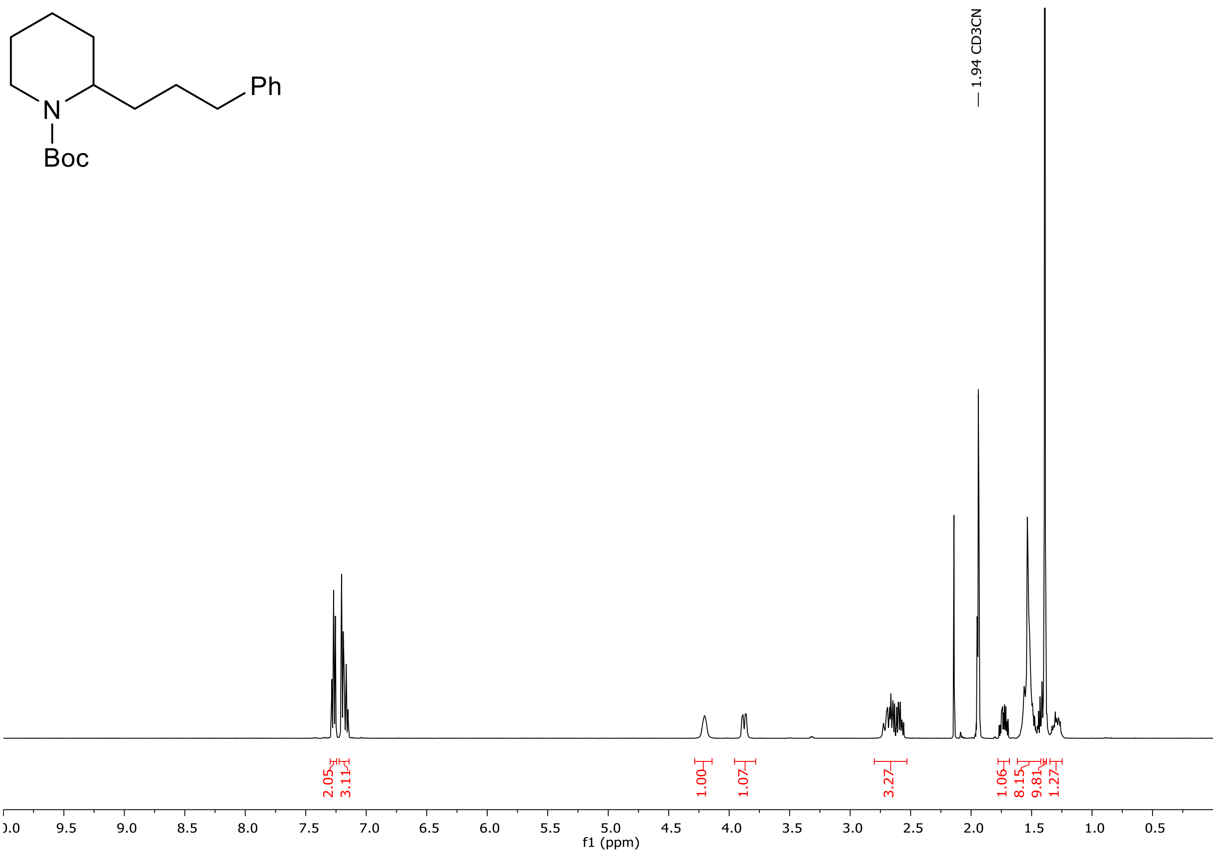

155.23
79.08
77.16 CDCl3
60.89
46.66
31.47
28.71
23.54
15.98
4.49
1.79
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

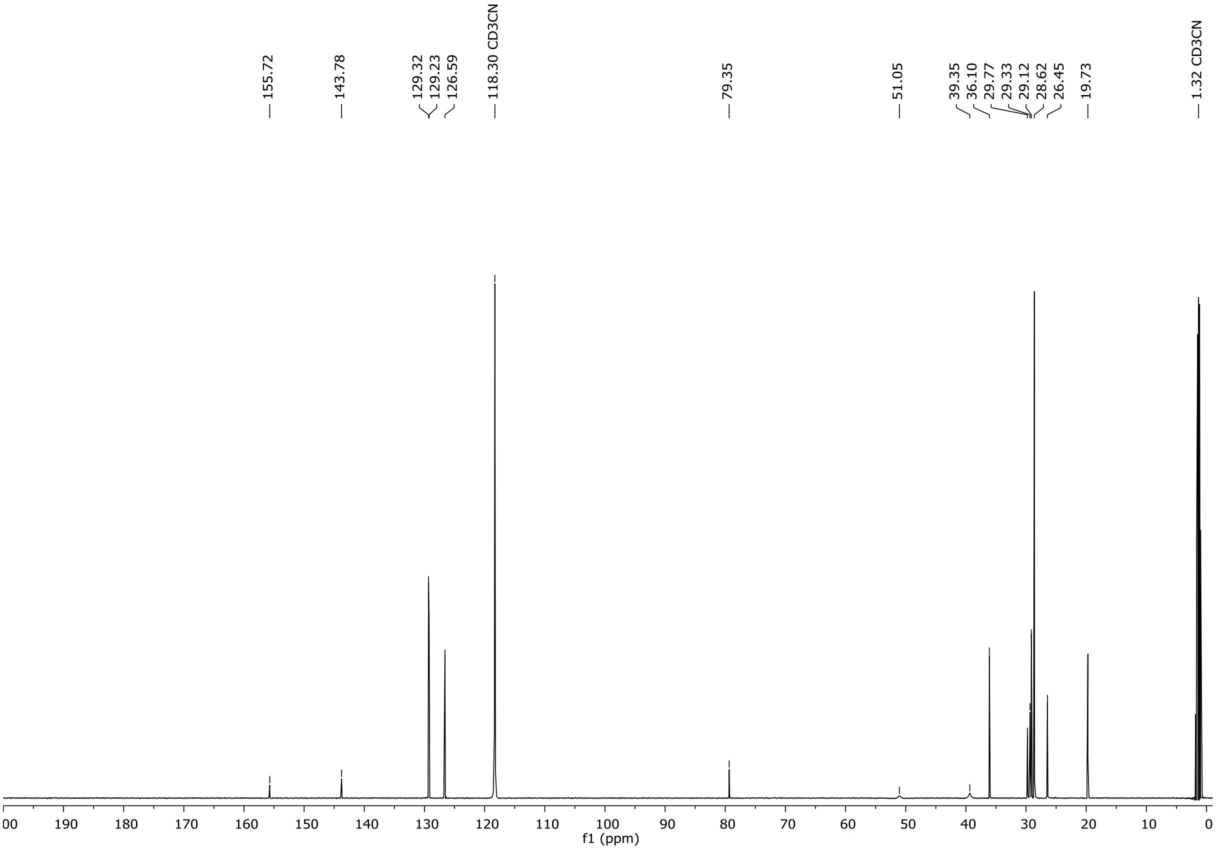

N
Cbz
O
7.26 CDCl3
4.91
2.00
1.07
2.84
0.99
1.02
1.03
0.99
1.05
2.01
1.72
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

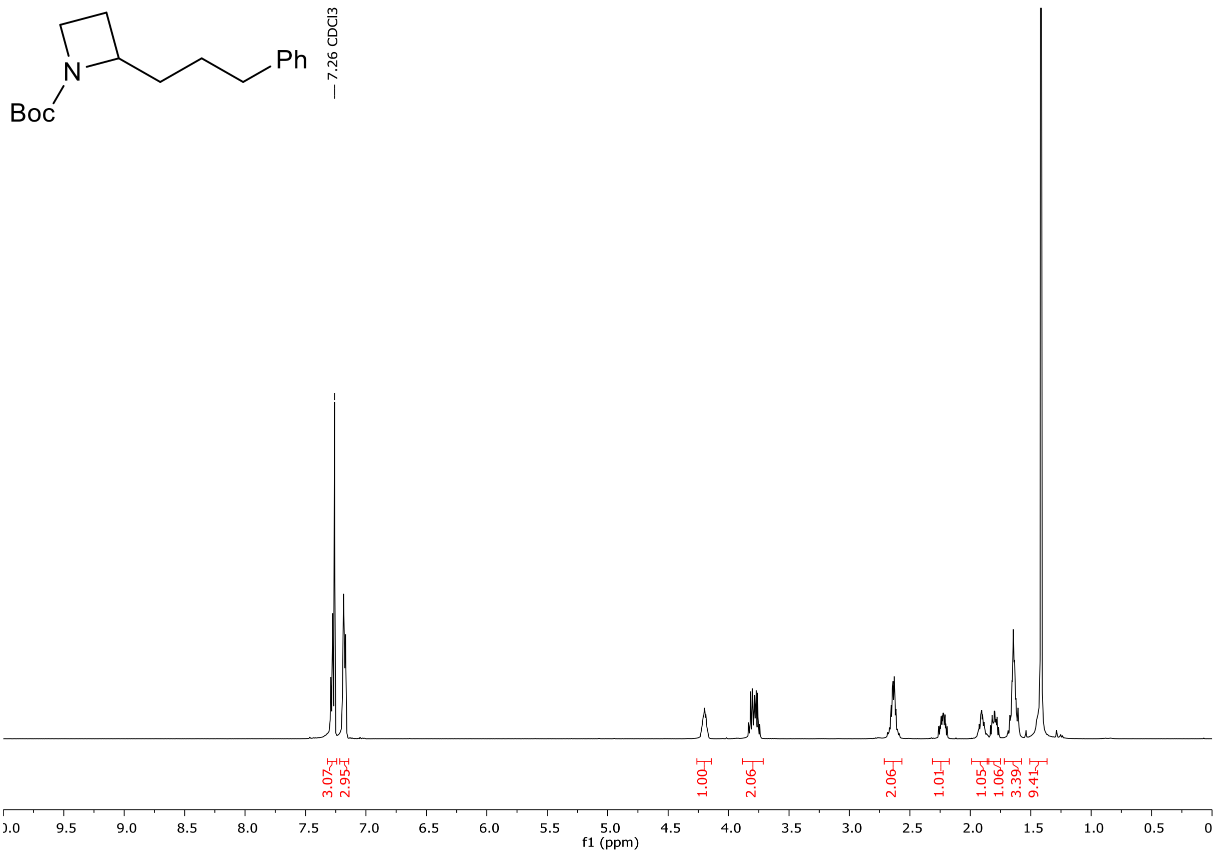

155.58
155.25
136.91
136.44
128.64
128.58
128.37
128.04
127.88
77.16 CDCl3
76.65
76.49
73.78
67.28
66.81
59.79
59.18
47.36
47.09
40.24
29.24
28.47
23.87
23.09
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

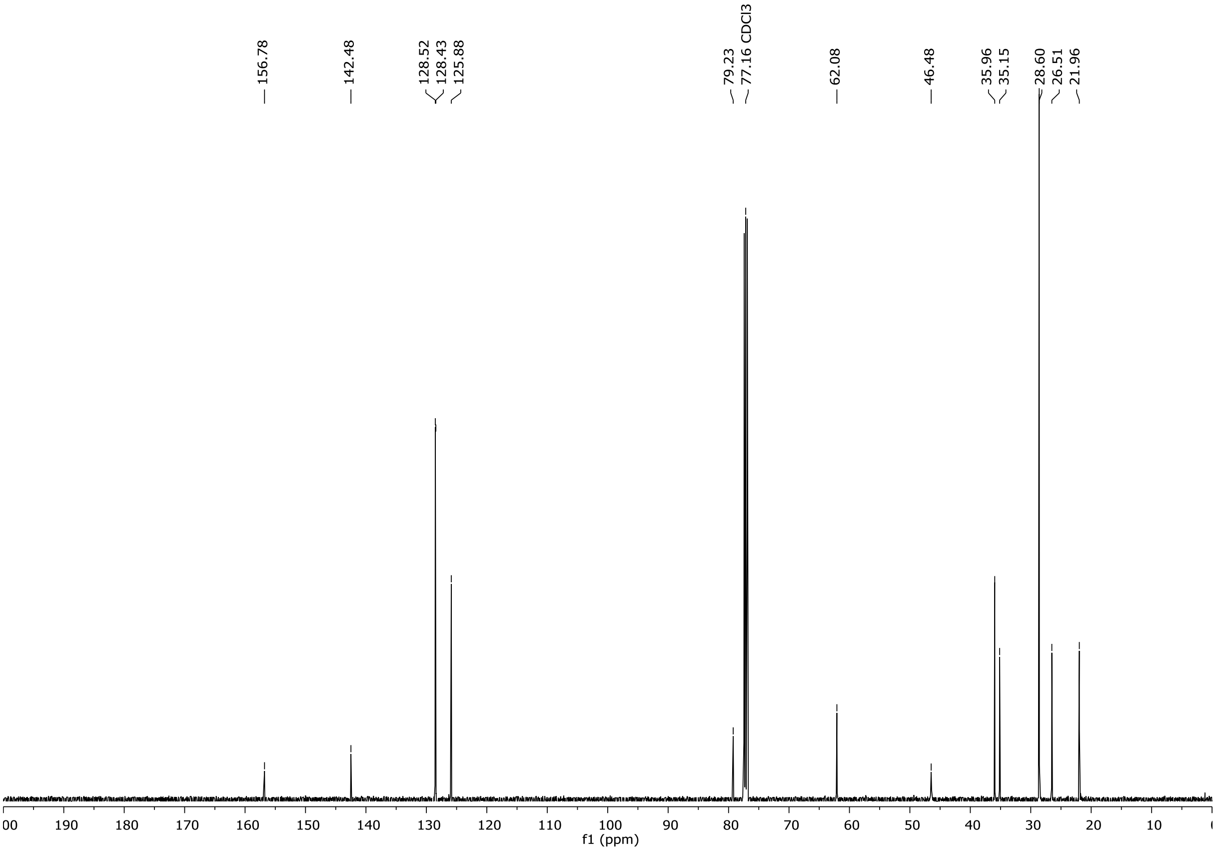

N
Cbz
Me
Me
7.26 CDCl3
4.94
2.00
1.00
1.01
0.98
1.00
4.18
6.23
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

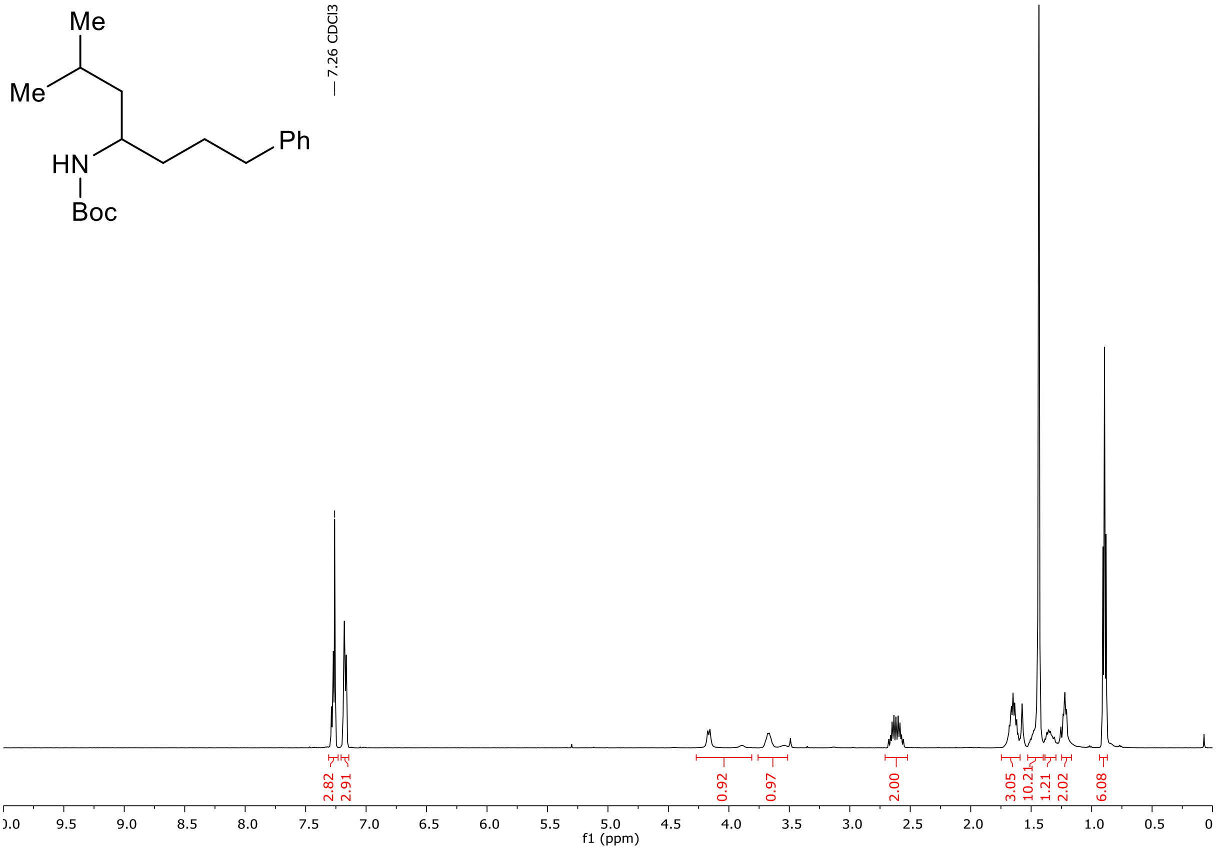

155.67
155.38
137.36
137.20
128.55
127.91
127.87
77.16 CDCl3
66.79
66.56
63.14
62.53
47.42
47.13
30.85
30.02
26.62
25.72
24.50
23.79
19.64
16.98
16.84
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

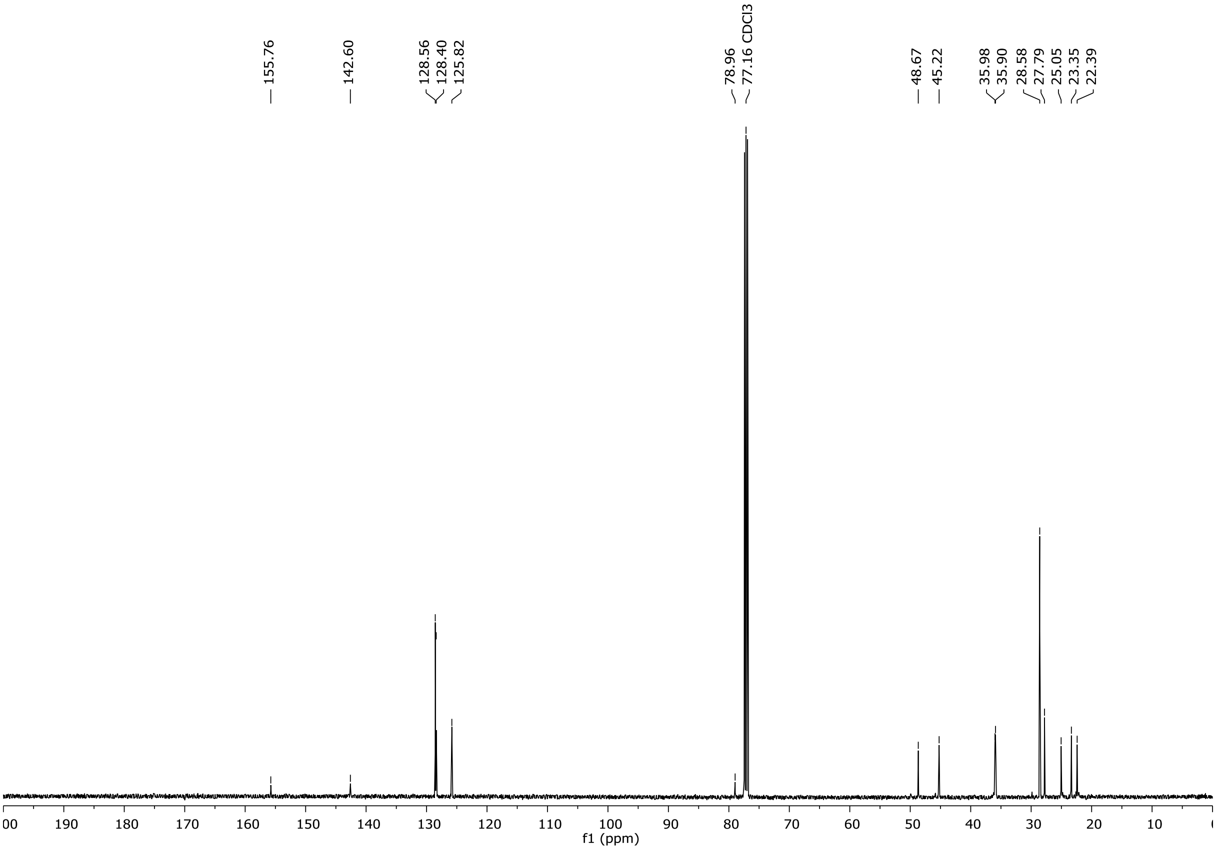

Ph
N
Boc
1.94 CD3CN
2.05
3.11
1.00
1.07
3.27
1.06
8.15
9.81
1.27
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

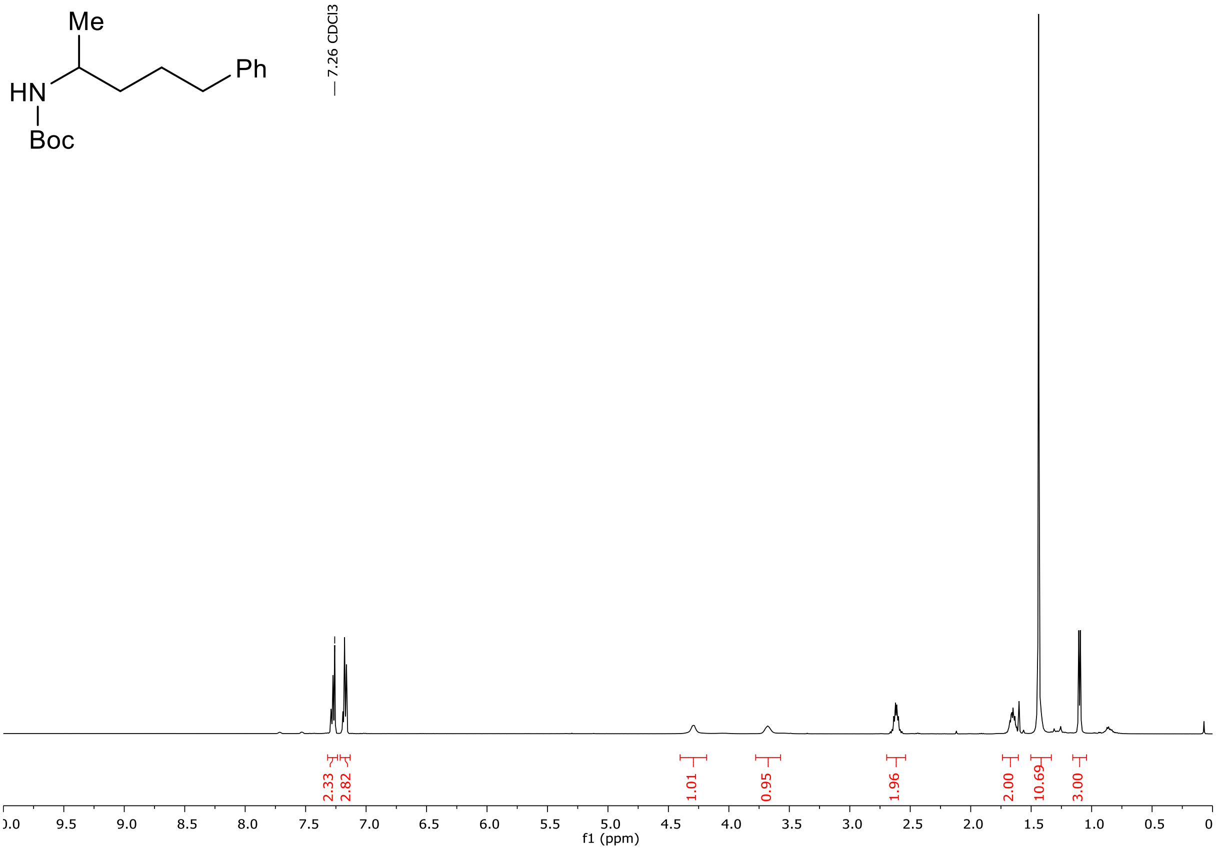

155.72
143.78
129.32
129.23
126.59
118.30 CD3CN
79.35
51.05
39.35
36.10
29.77
29.33
29.12
28.62
26.45
19.73
1.32 CD3CN
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

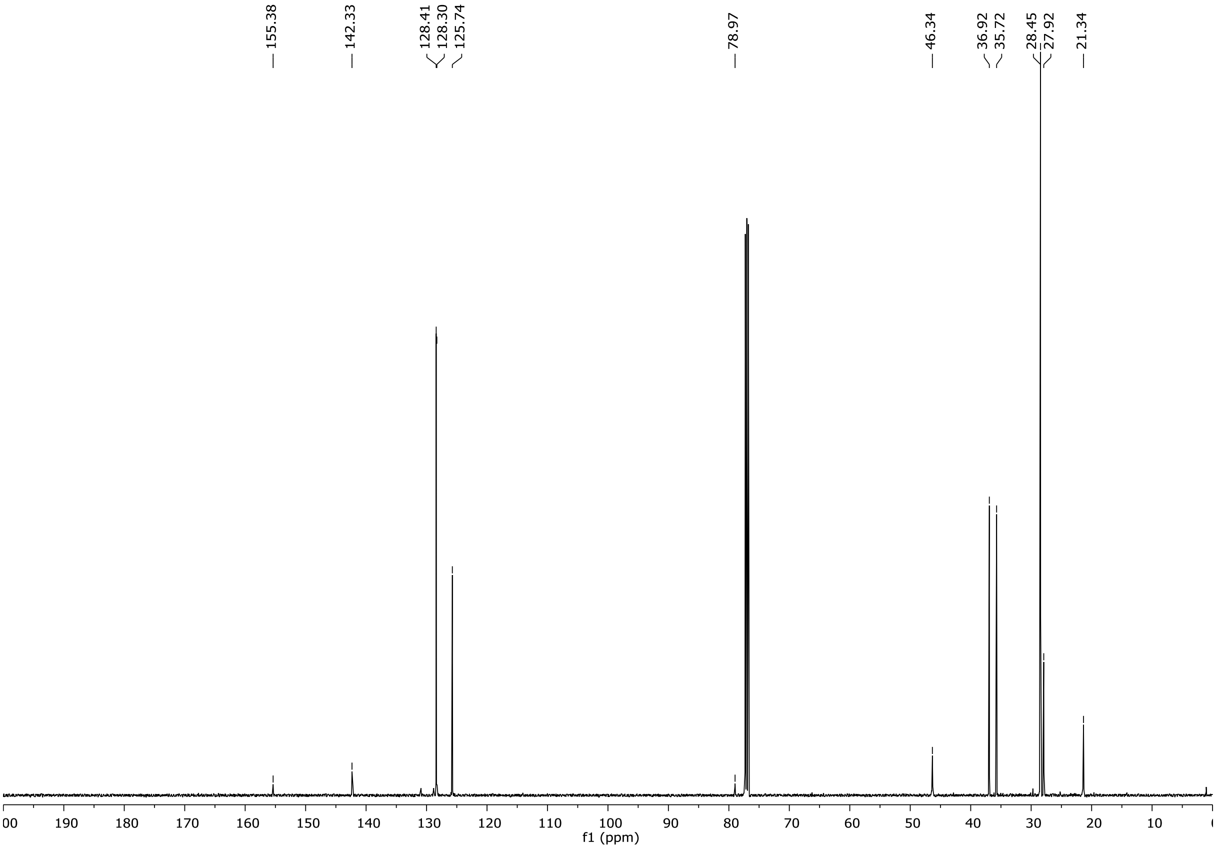

N
Boc
Ph
7.26 CDCl3
3.07
2.95
1.00
2.06
2.06
1.01
1.05
1.06
3.39
9.41
).0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

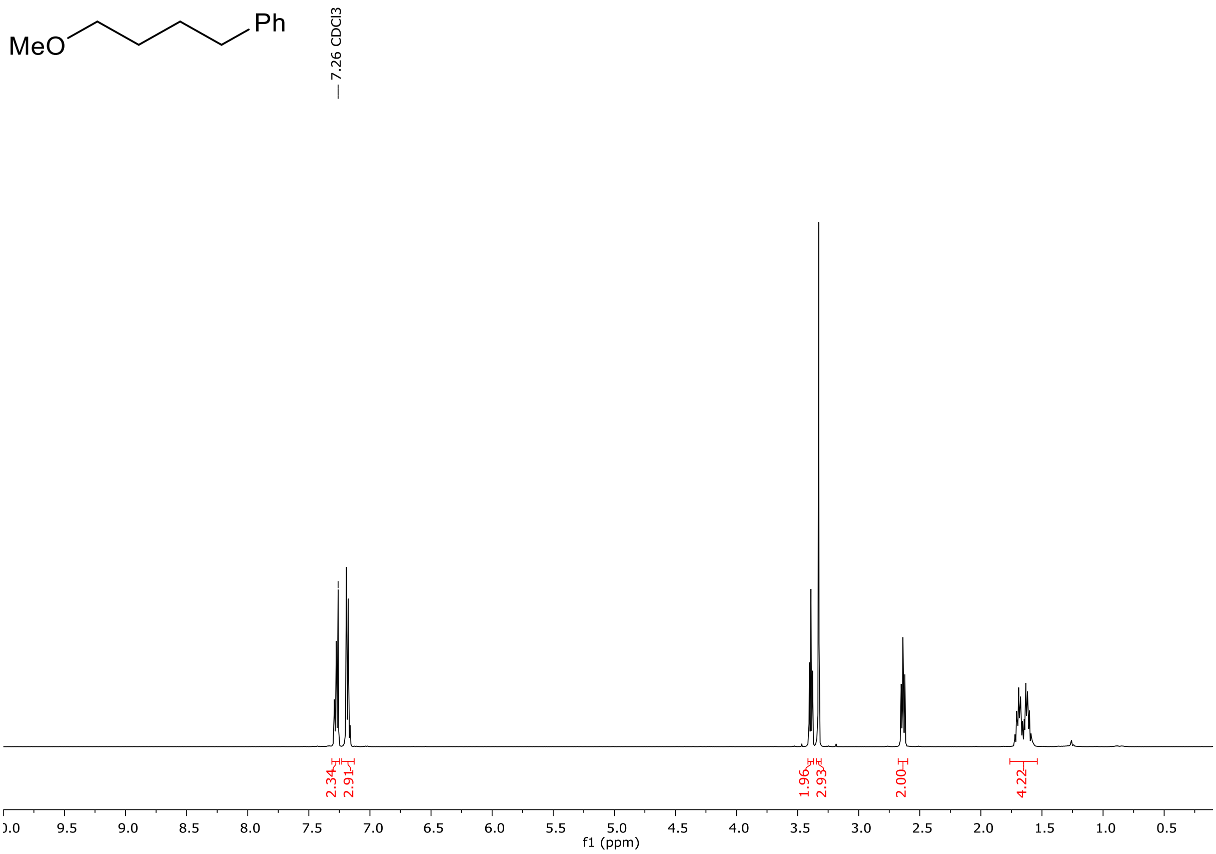

156.78
142.48
128.52
128.43
125.88
79.23
77.16 CDCl3
62.08
46.48
35.96
35.15
28.60
26.51
21.96
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

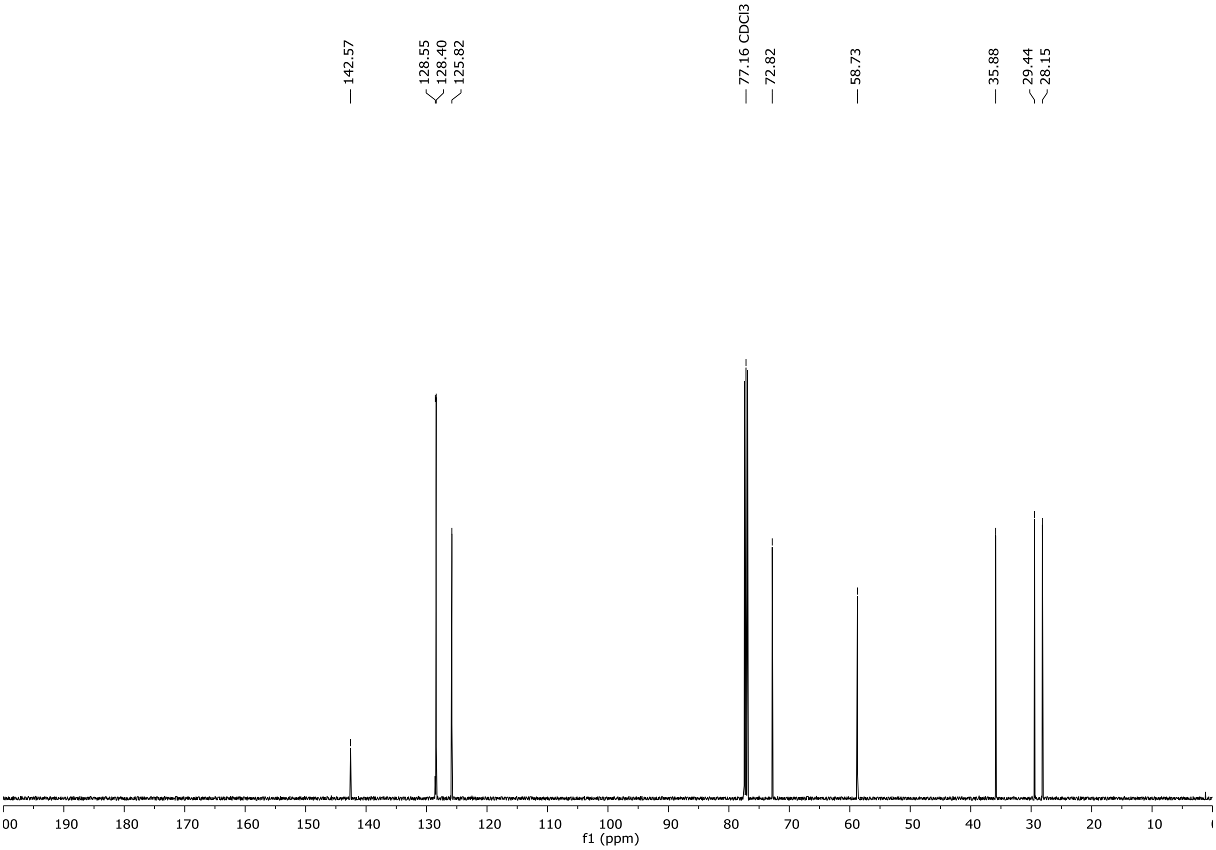

Me
Me
HN
Boc
Ph
7.26 CDCl3
2.82
2.91
0.92
0.97
2.00
3.05
10.21
1.21
2.02
6.08
).0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

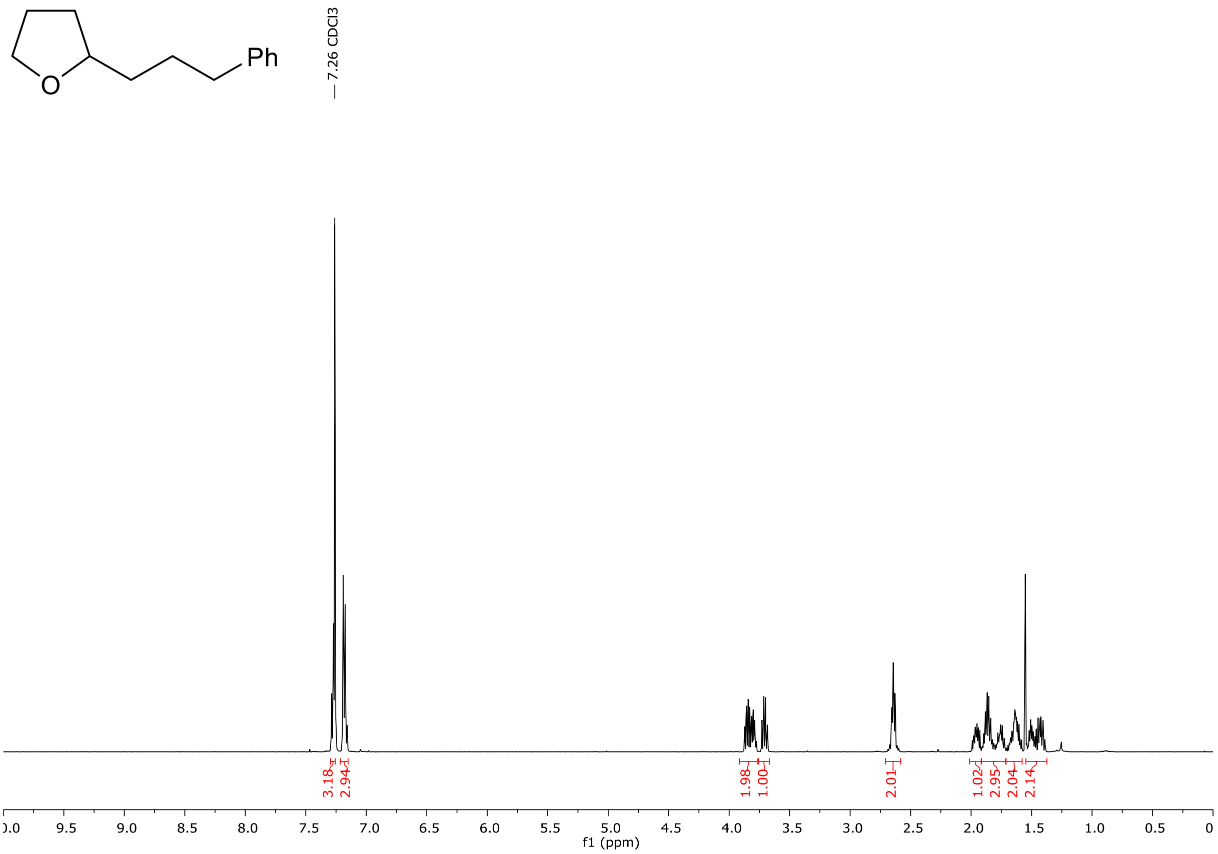

155.76
142.60
128.56
128.40
125.82
78.96
77.16 CDCl3
48.67
45.22
35.98
35.90
28.58
27.79
25.05
23.35
22.39
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

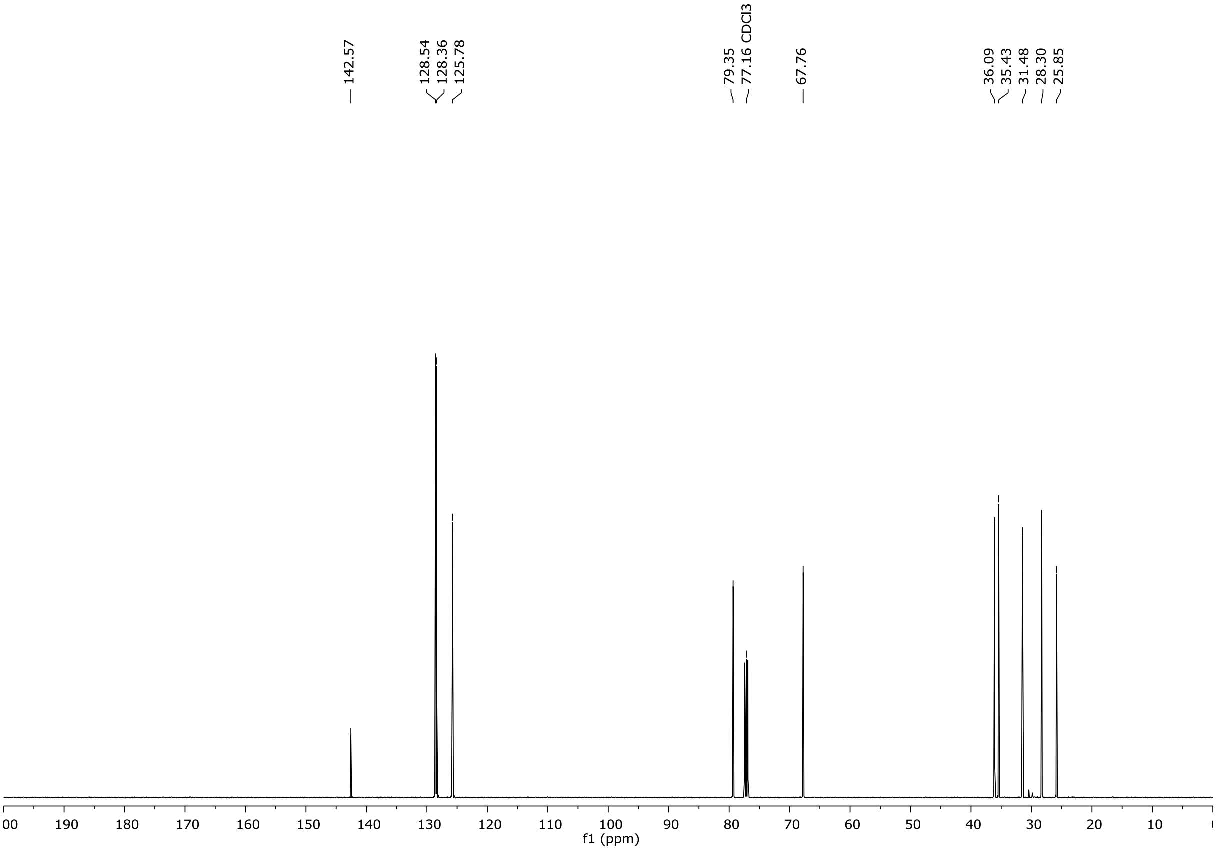

Me
HN
Boc
Ph
7.26 CDCl3
2.33
2.82
1.01
0.95
1.96
2.00
10.69
3.00
0.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0
f1 (ppm)

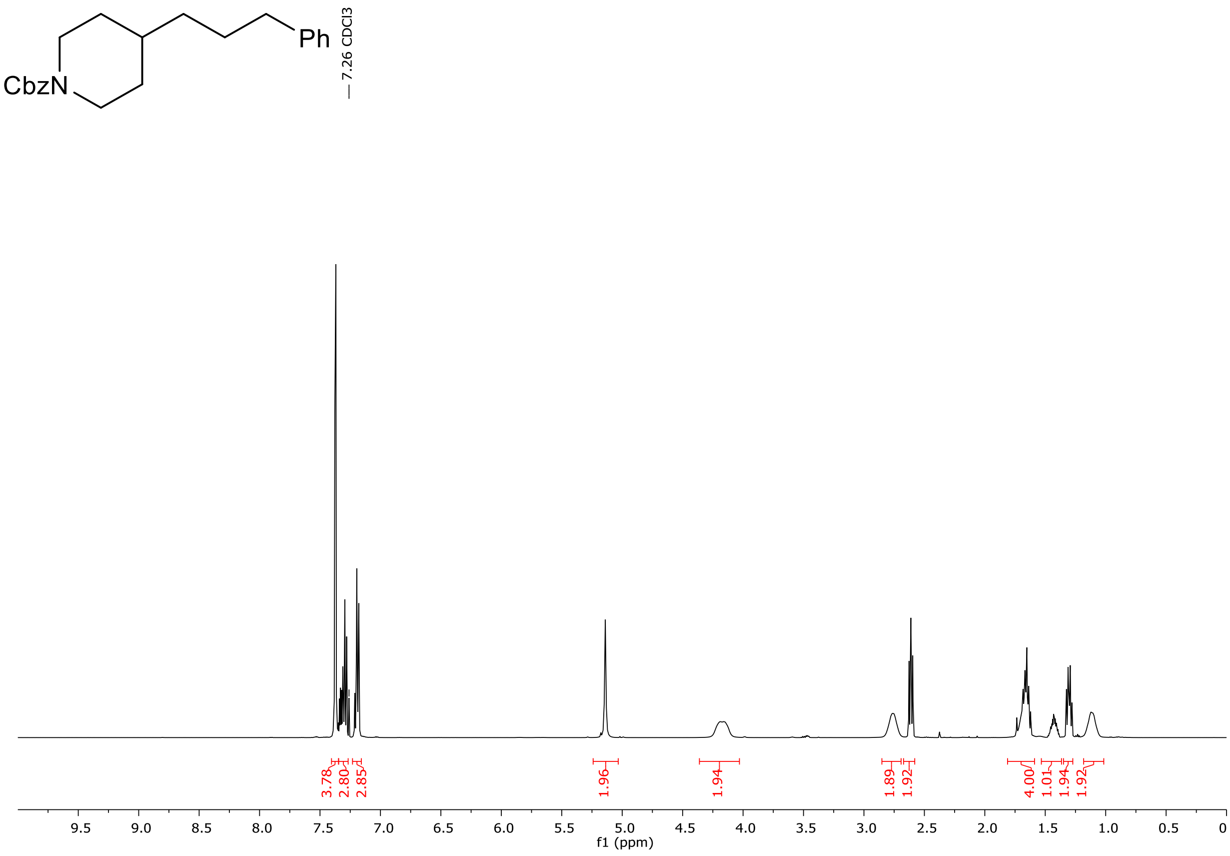

155.38
142.33
128.41
128.30
125.74
78.97
46.34
36.92
35.72
28.45
27.92
21.34
00 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

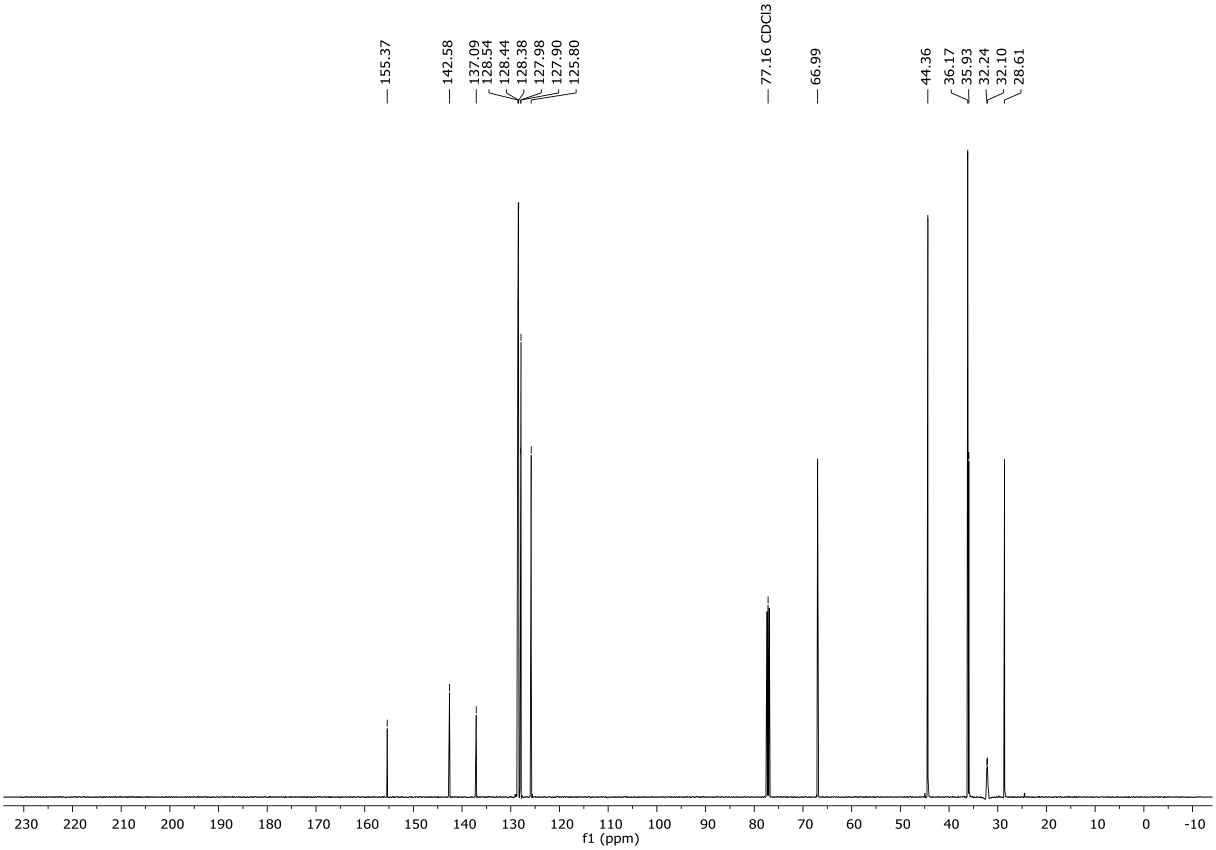

MeO
Ph
7.26 CDCl3
2.34
2.91
1.96
2.93
2.00
4.22
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

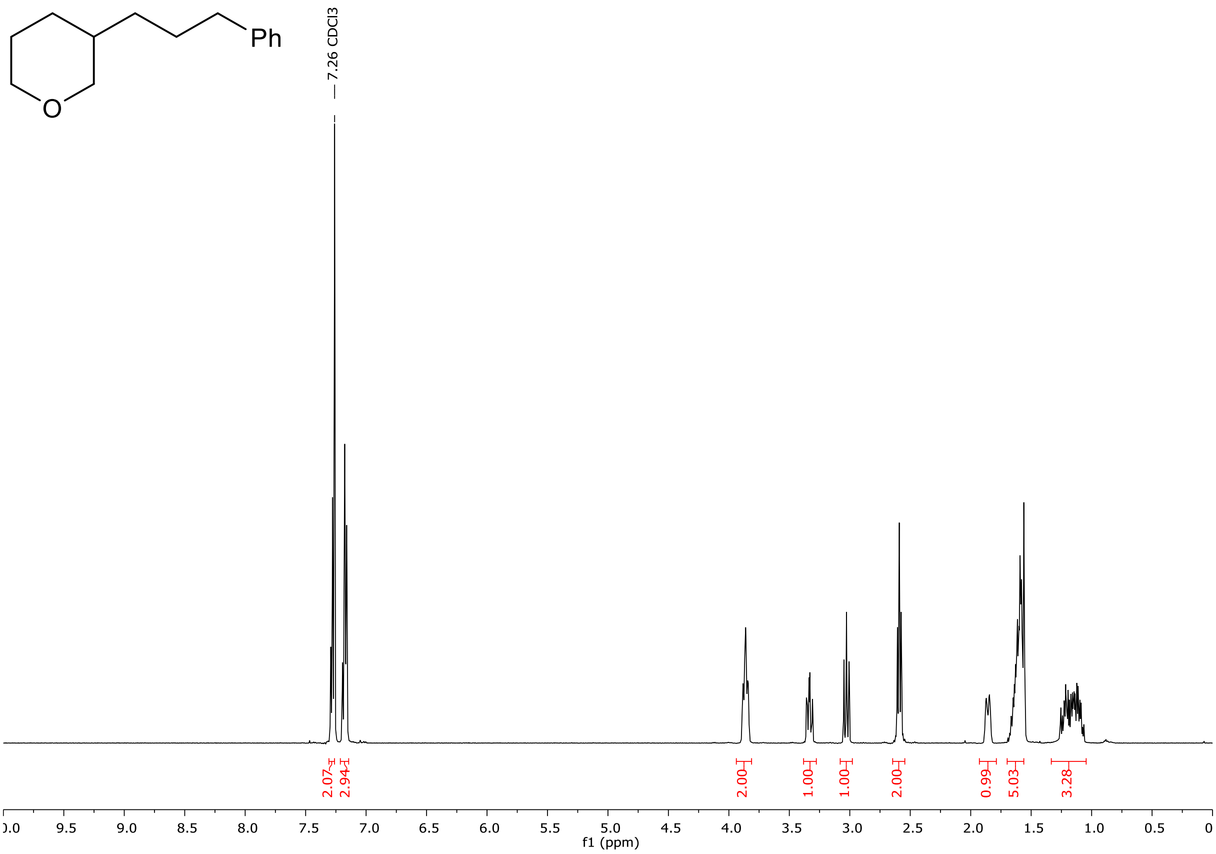

142.57
128.55
128.40
125.82
77.16 CDCl3
72.82
58.73
35.88
29.44
28.15
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

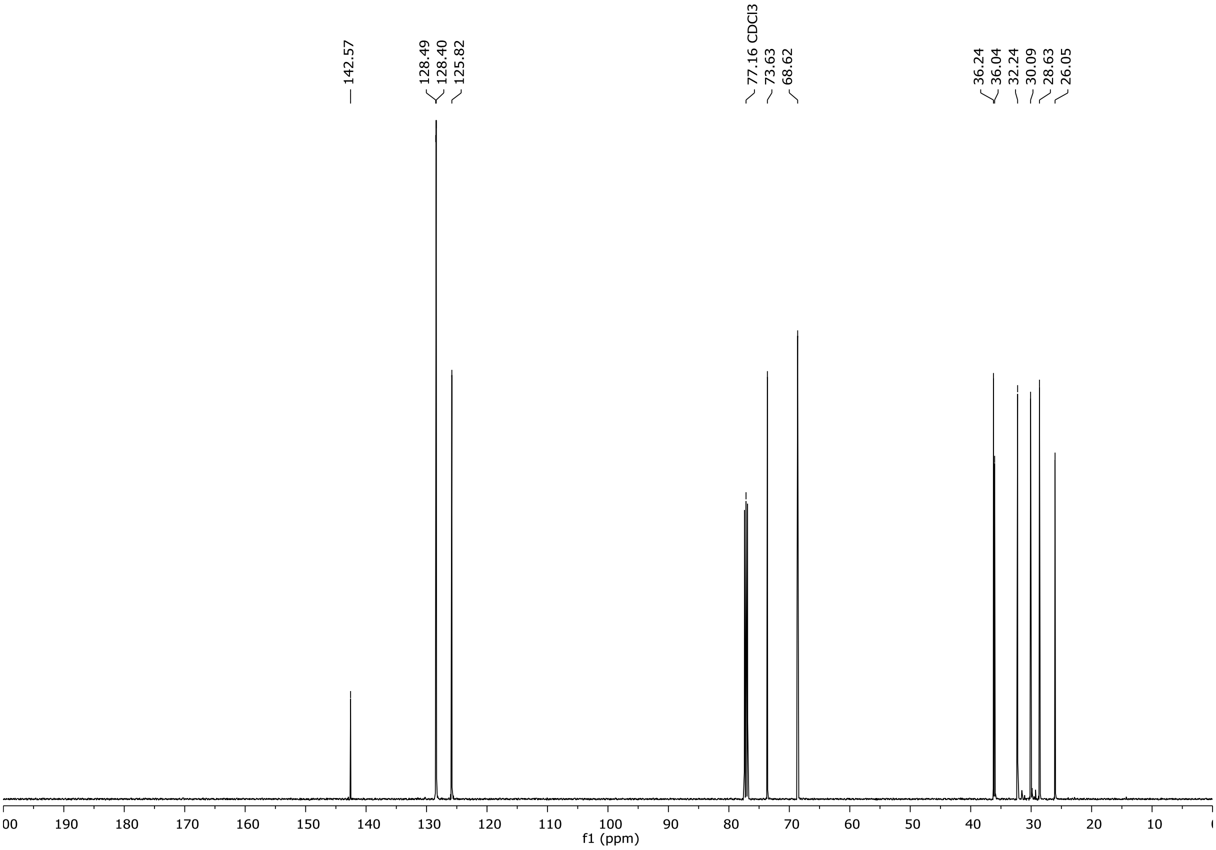

O
Ph
7.26 CDCl3
3.18
2.94
1.98
1.00
2.01
1.02
2.95
2.04
2.14
).0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

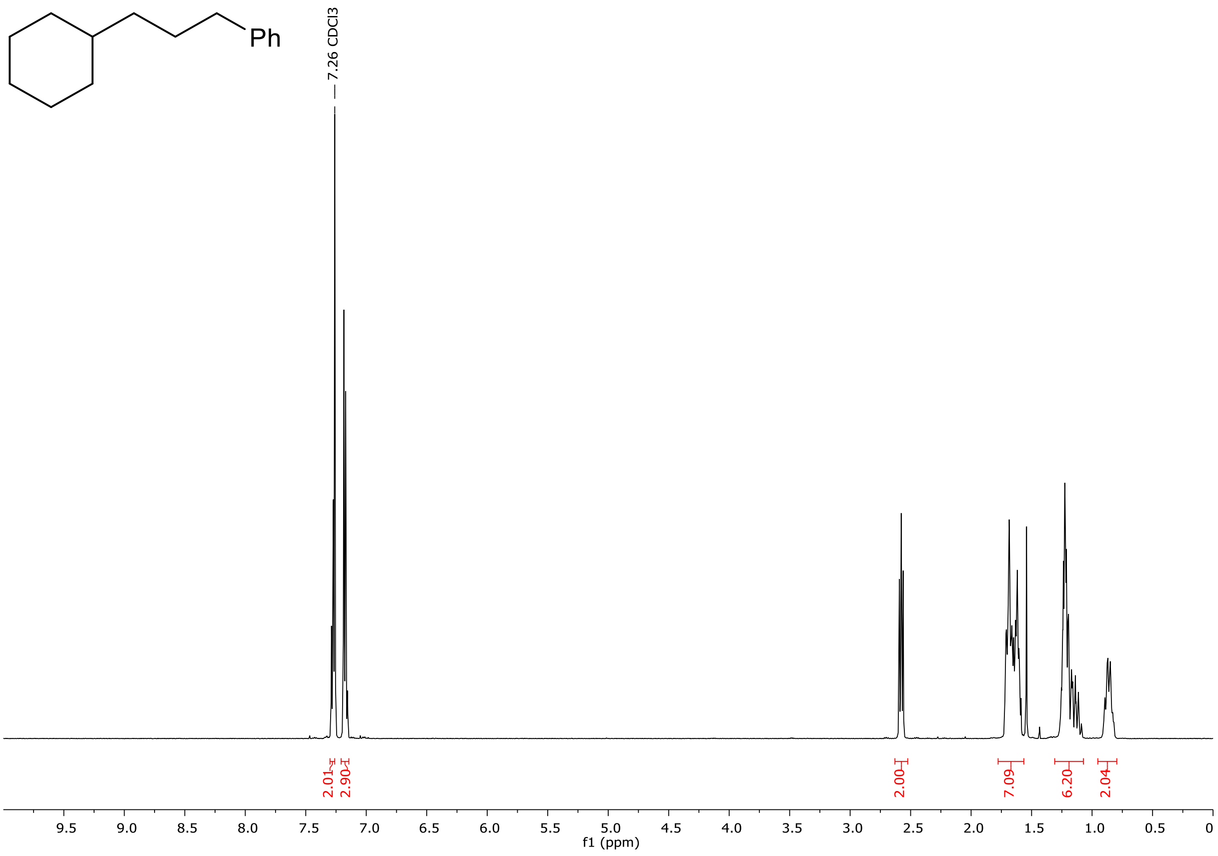

142.57
128.54
128.36
125.78
79.35
77.16 CDCl3
67.76
36.09
35.43
31.48
28.30
25.85
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

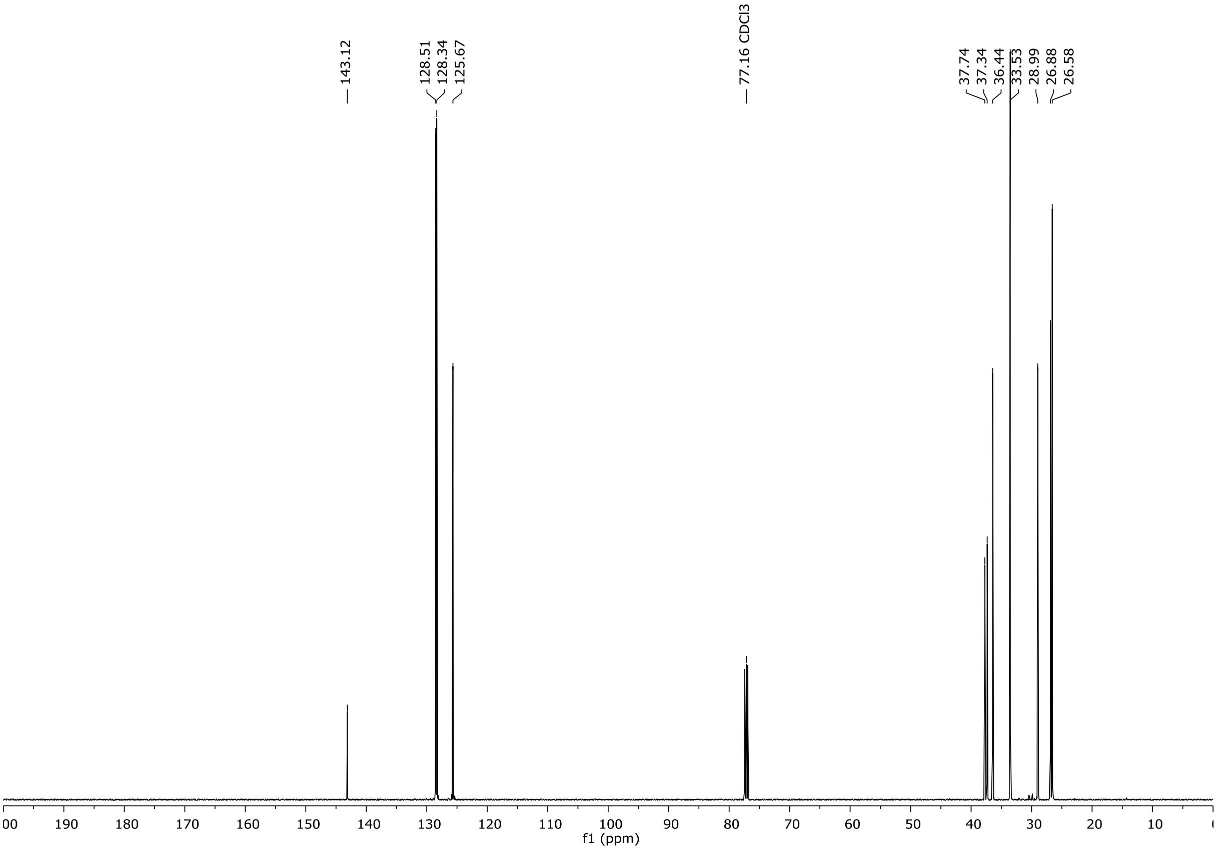

CbzN
Ph
7.26 CDCl3
3.78
2.80
2.85
1.96
1.94
1.89
1.92
4.00
1.01
1.94
1.92
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

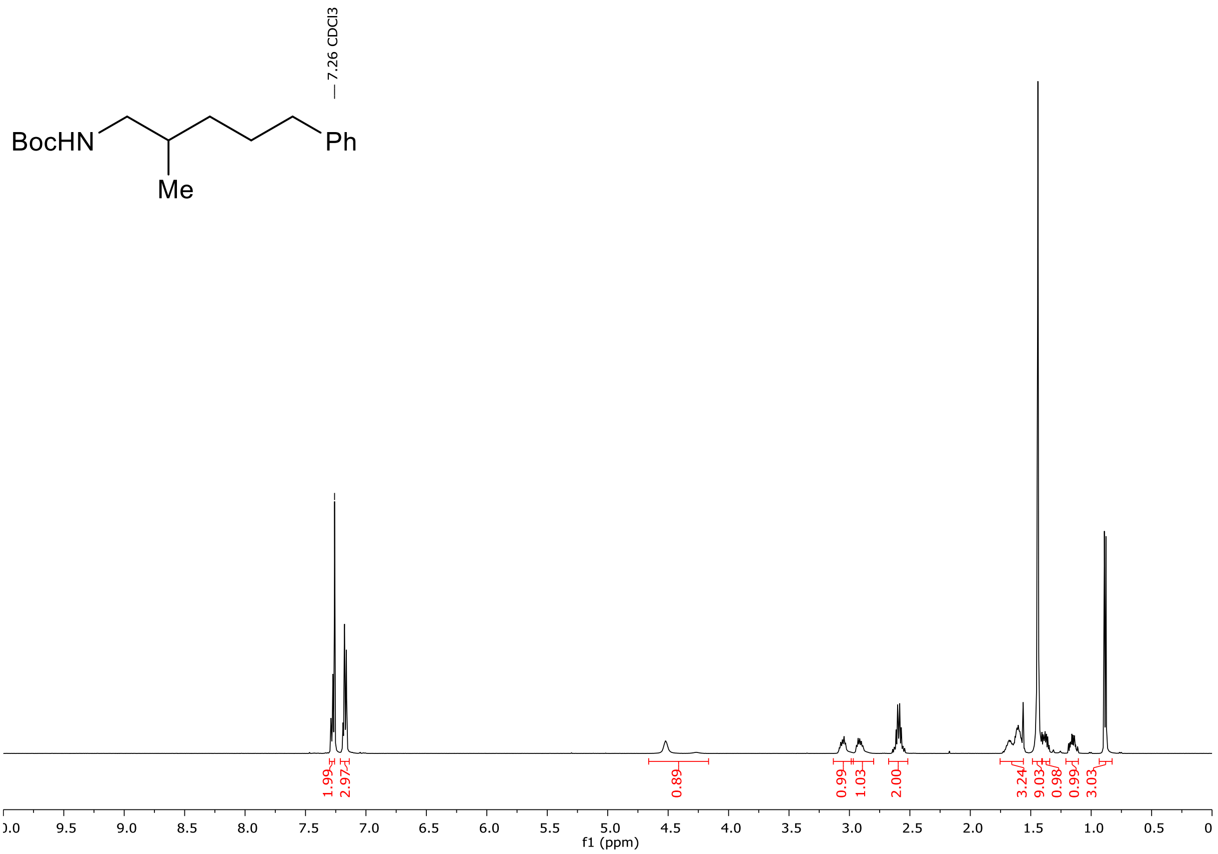

155.37
142.58
137.09
128.54
128.44
128.38
127.98
127.90
125.80
77.16 CDCl3
66.99
44.36
36.17
35.93
32.24
32.10
28.61
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

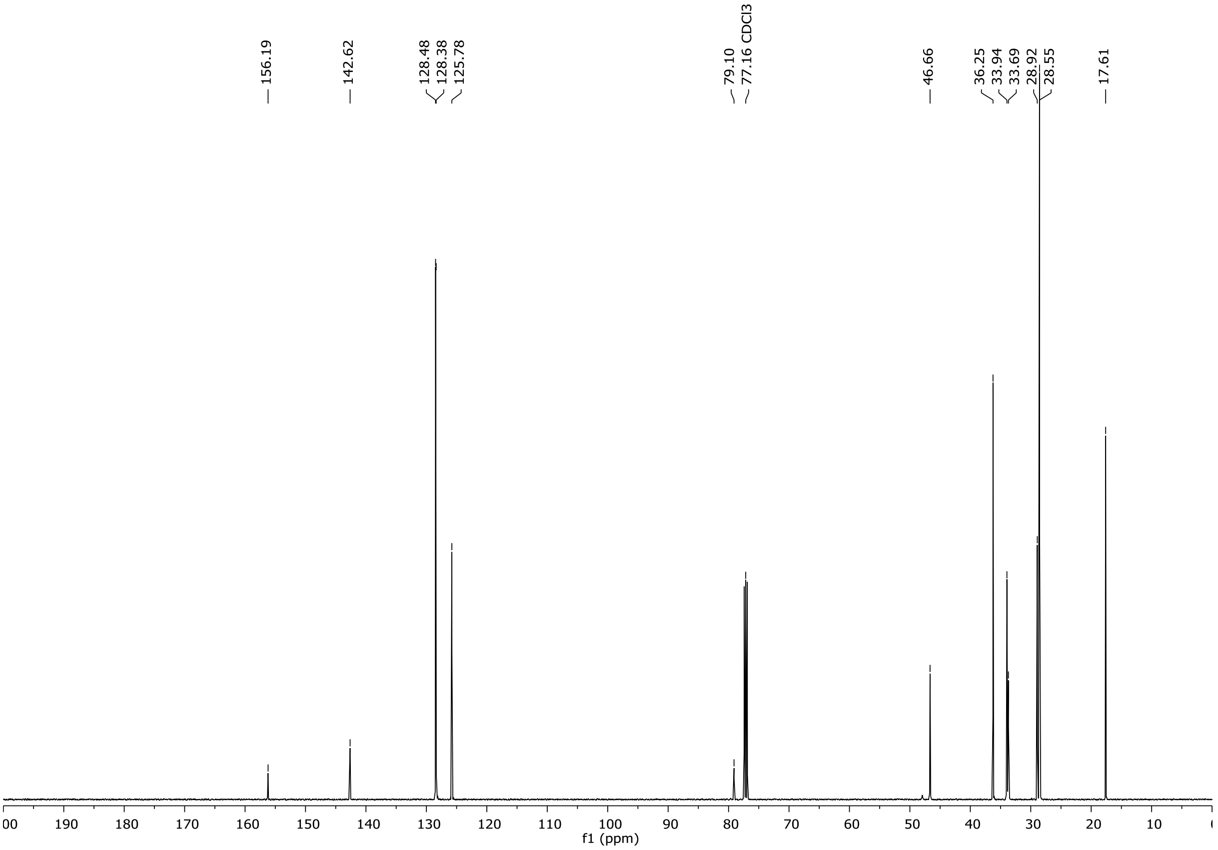

Ph
O
7.26 CDCl3
2.07
2.94
2.00
1.00
1.00
2.00
0.99
5.03
3.28
).0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

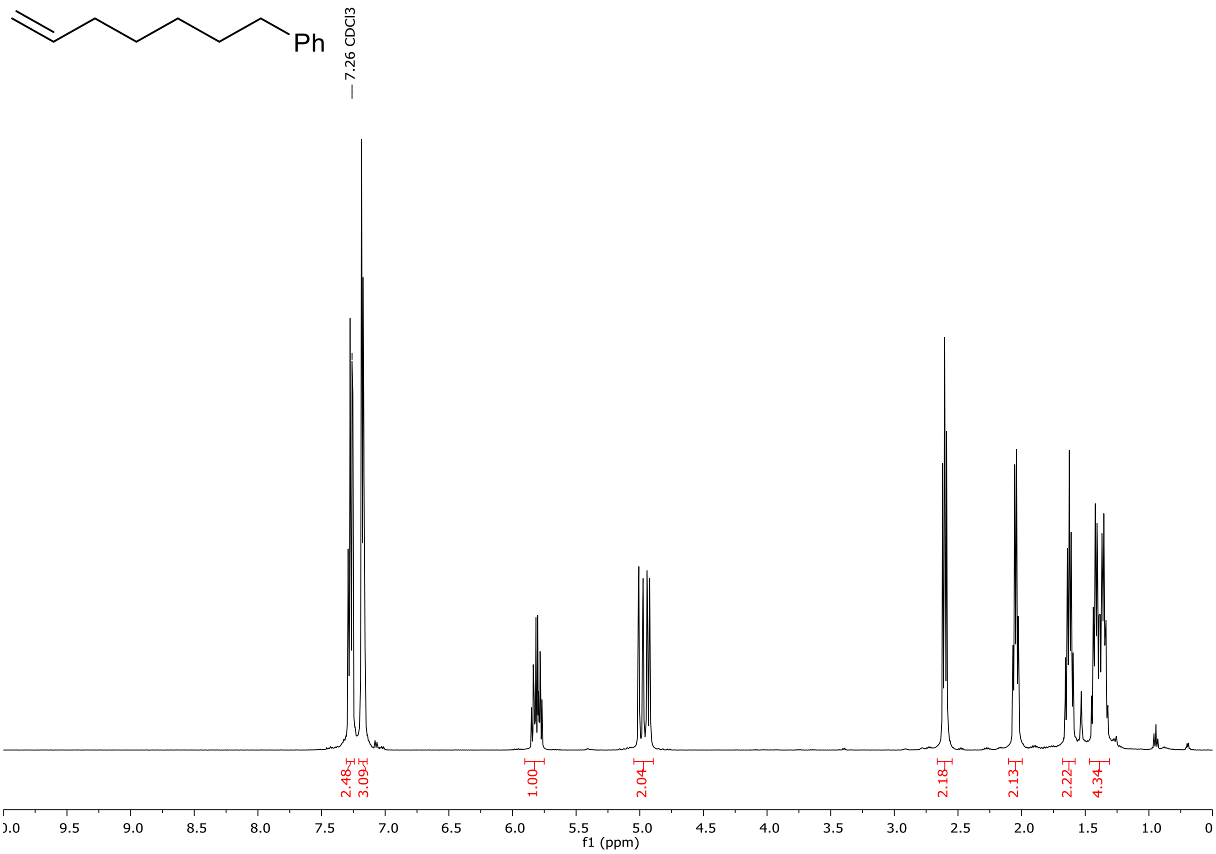

142.57
128.49
128.40
125.82
77.16 CDCl3
73.63
68.62
36.24
36.04
32.24
30.09
28.63
26.05
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

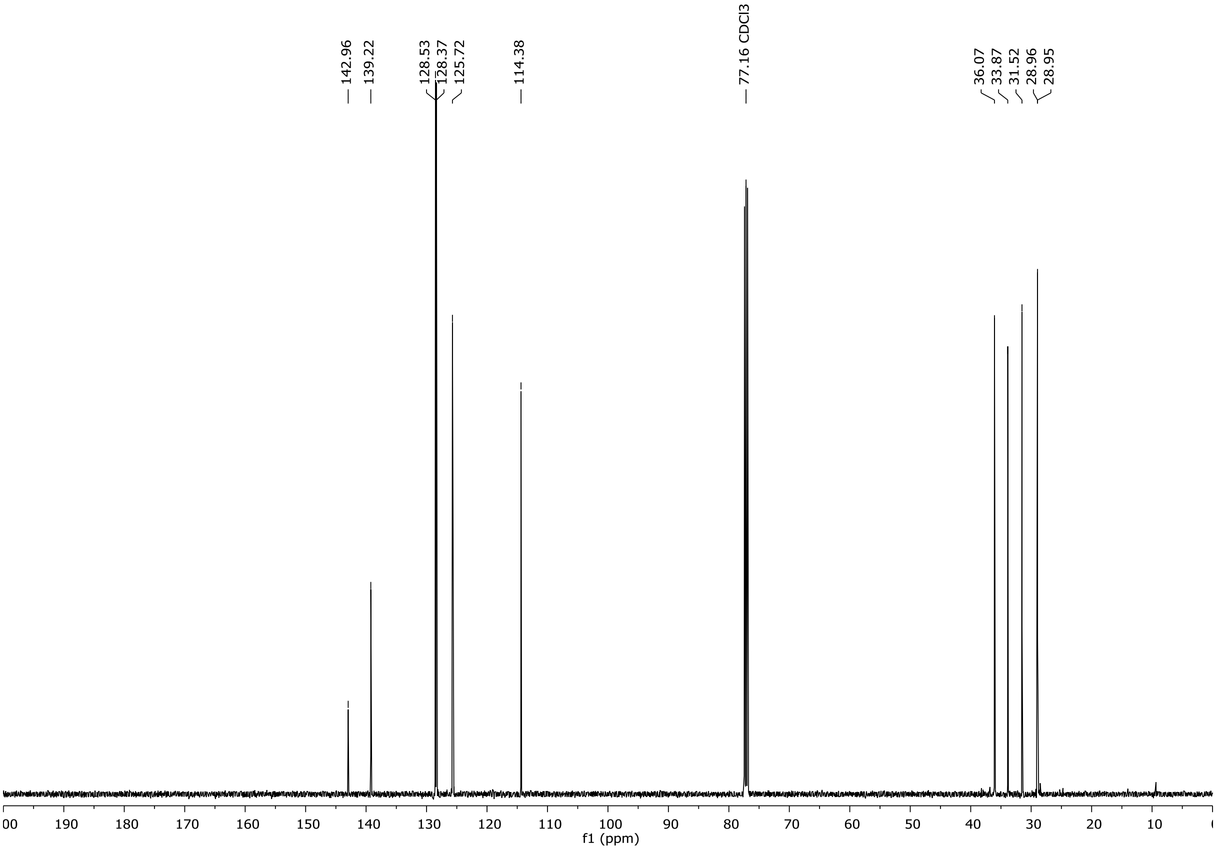

Ph
7.26 CDCl3
2.01
2.90
2.00
7.09
6.20
2.04
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

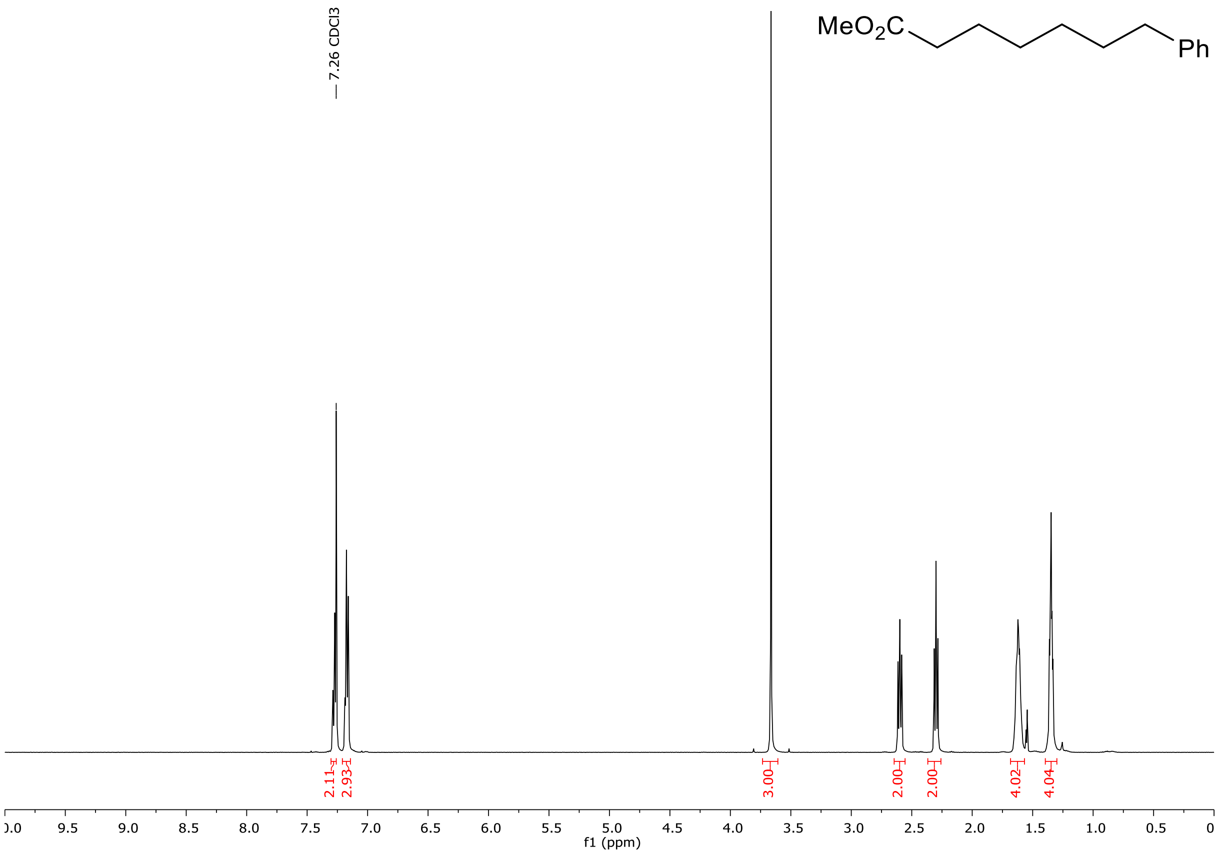

143.12
128.51
128.34
125.67
77.16 CDCl3
37.74
37.34
36.44
33.53
28.99
26.88
26.58
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

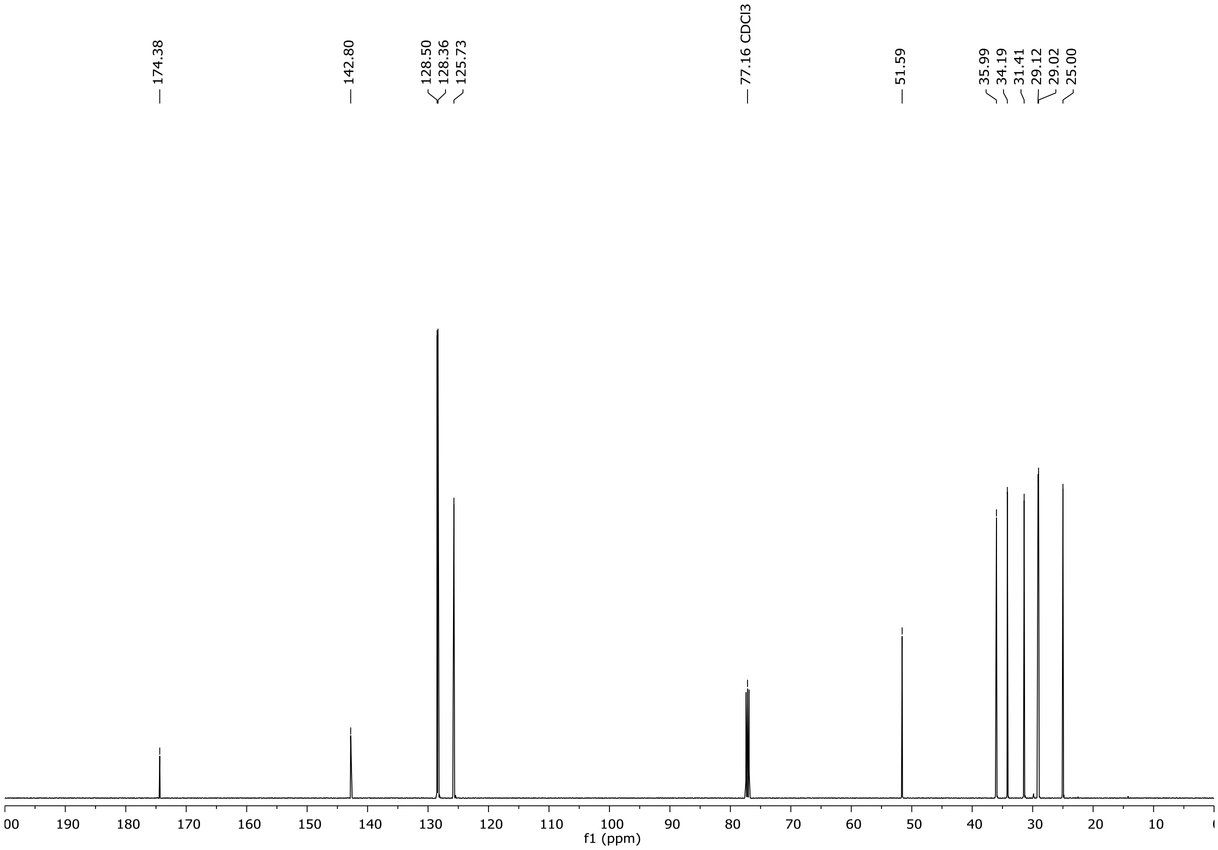

BocHN
Me
Ph
7.26 CDCl3
1.99
2.97
0.89
0.99
1.03
2.00
3.24
9.03
0.98
0.99
3.03
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)

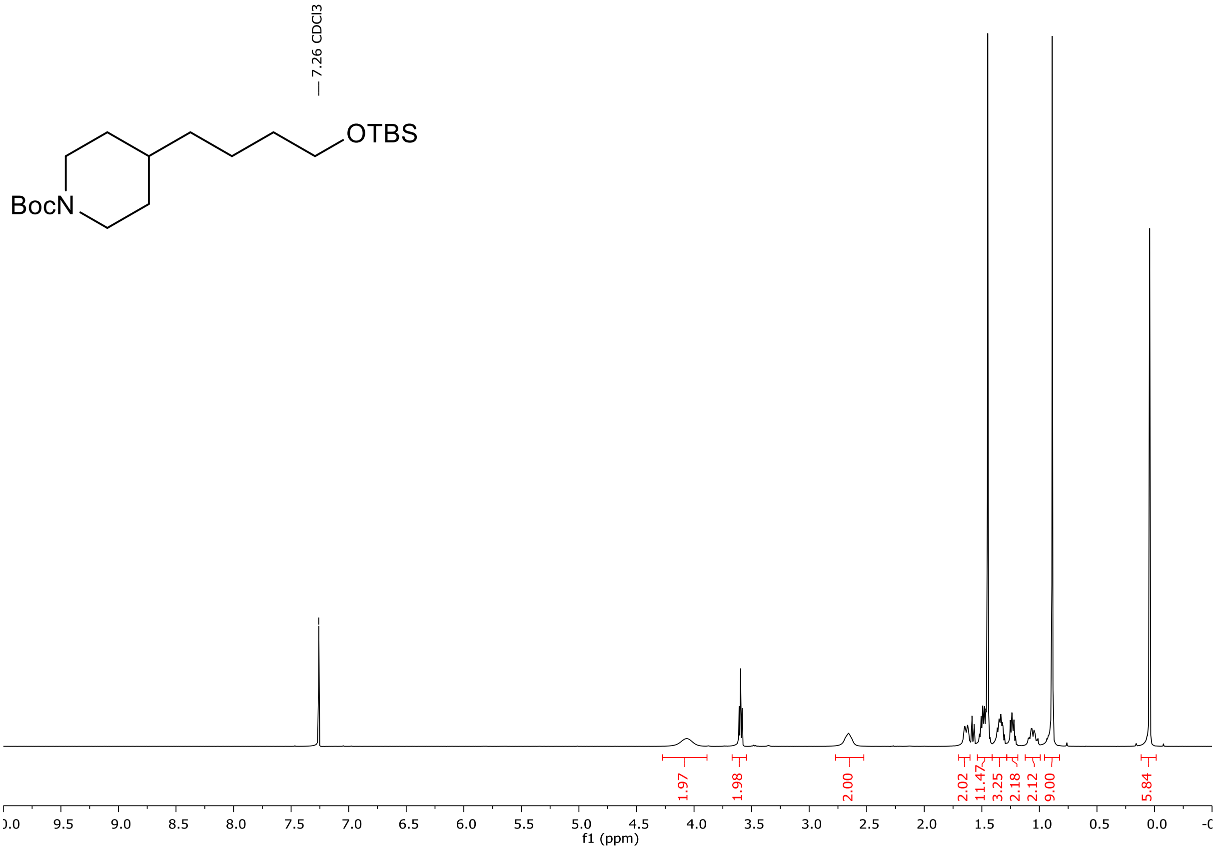

156.19
142.62
128.48
128.38
125.78
79.10
77.16 CDCl3
46.66
36.25
33.94
33.69
28.92
28.55
17.61
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


Ph
7.26 CDCl3
2.48
3.09
1.00
2.04
2.18
2.13
2.22
4.34
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
f1 (ppm)

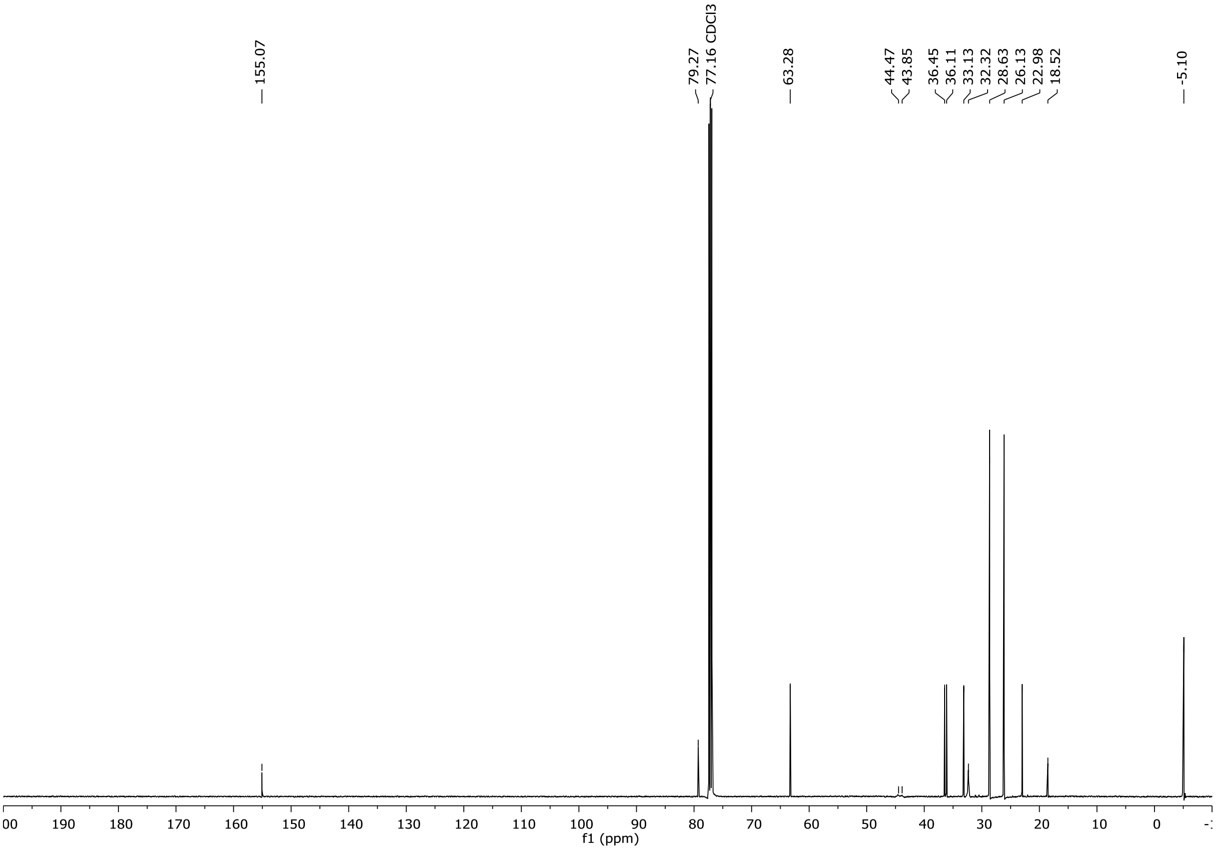

142.96
139.22
128.53
128.37
125.72
114.38
77.16 CDCl3
36.07
33.87
31.52
28.96
28.95
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


MeO2C
Ph
7.26 CDCl3
2.11
2.93
3.00
2.00
2.00
4.02
4.04
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
f1 (ppm)

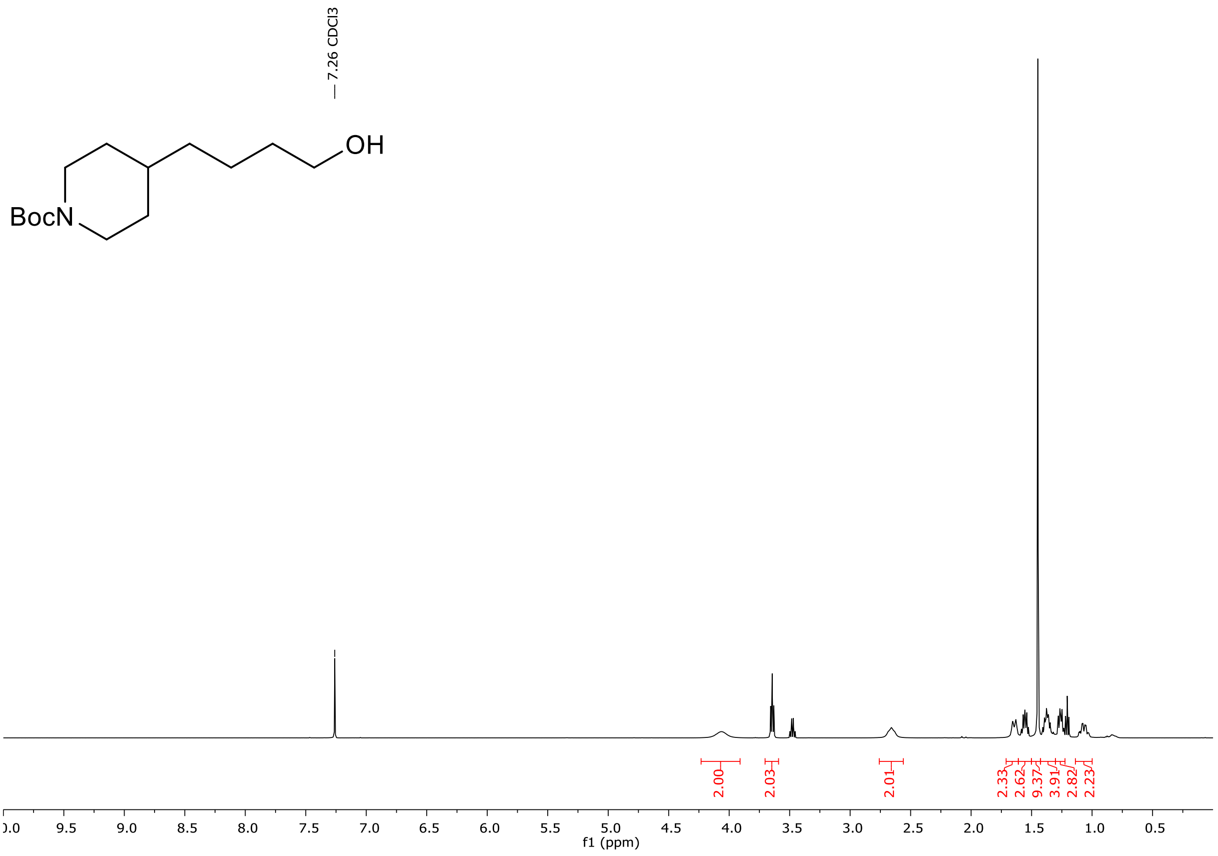

174.38
142.80
128.50
128.36
125.73
77.16 CDCl3
51.59
35.99
34.19
31.41
29.12
29.02
25.00
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

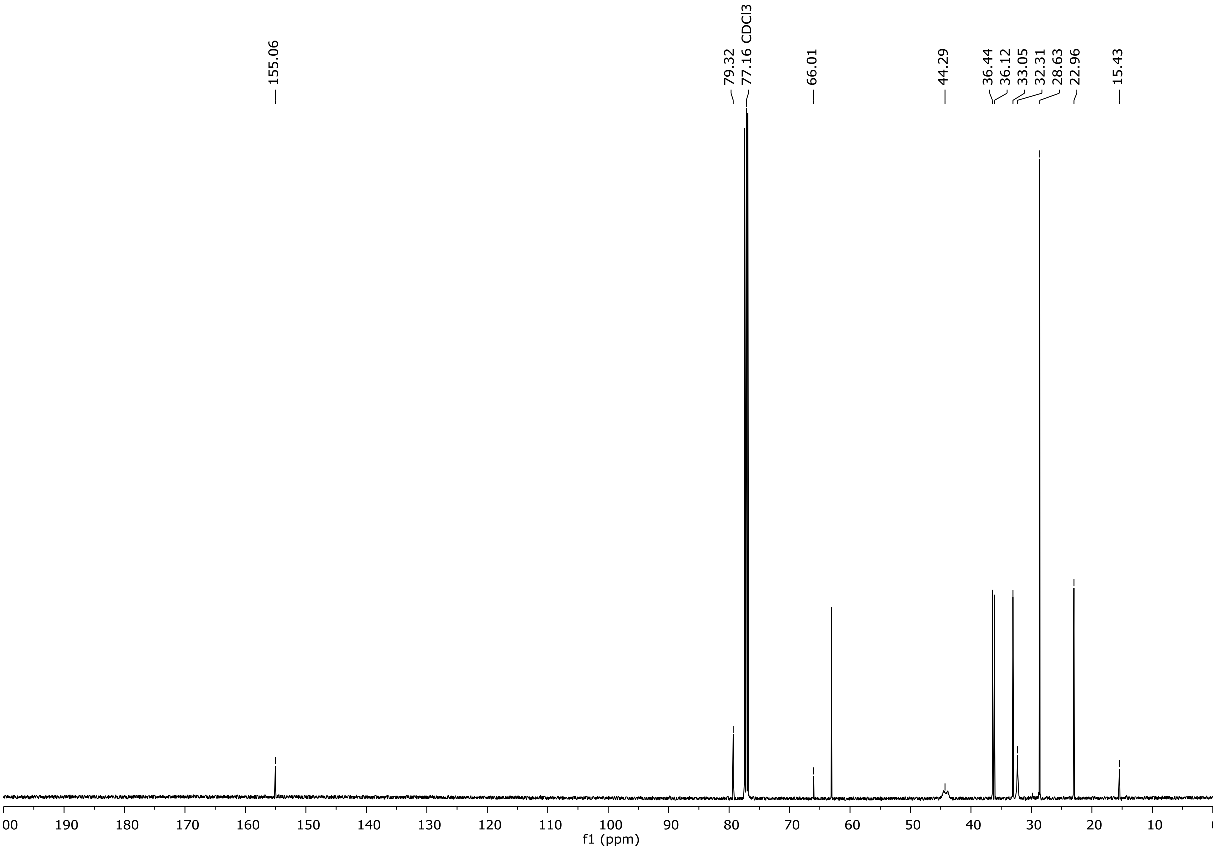


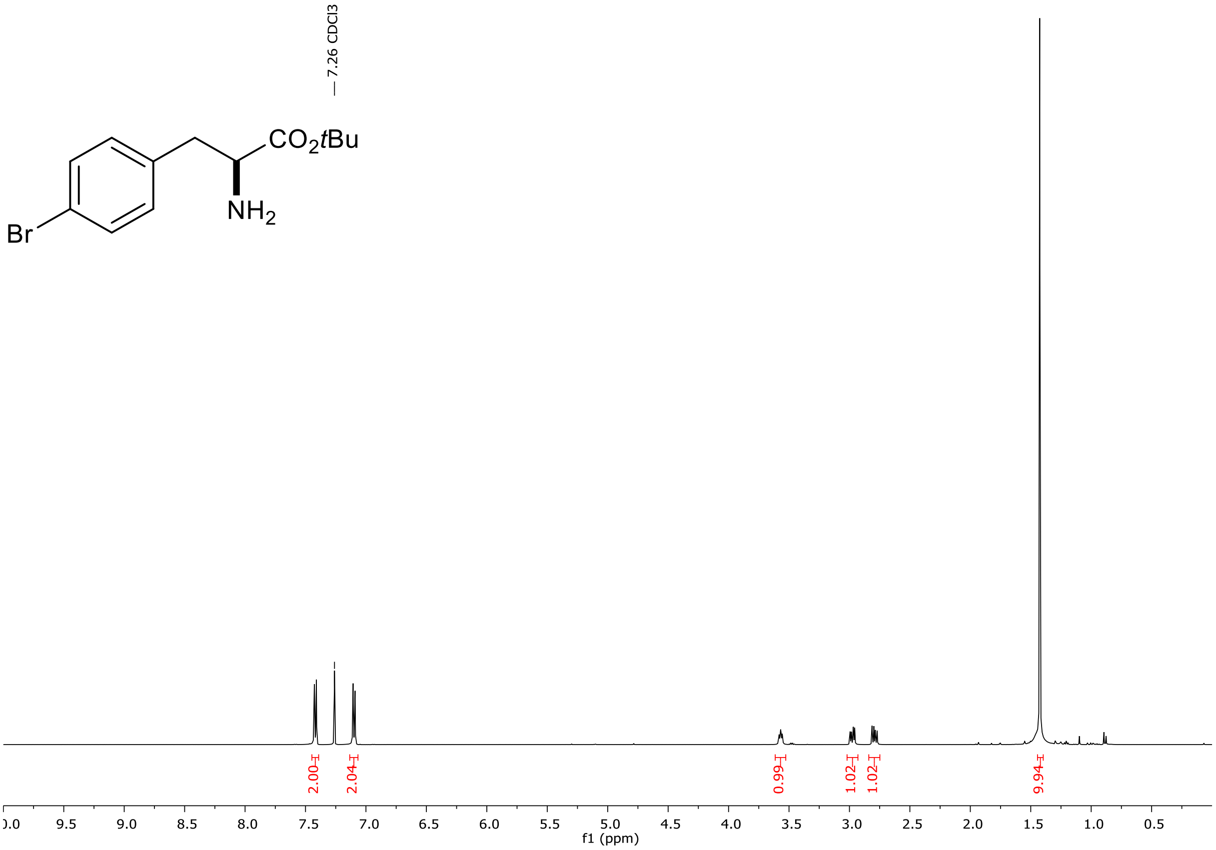
OTBS
BocN
7.26 CDCl3
1.97
1.98
2.00
2.02
11.47
3.25
2.18
2.12
9.00
5.84
0.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

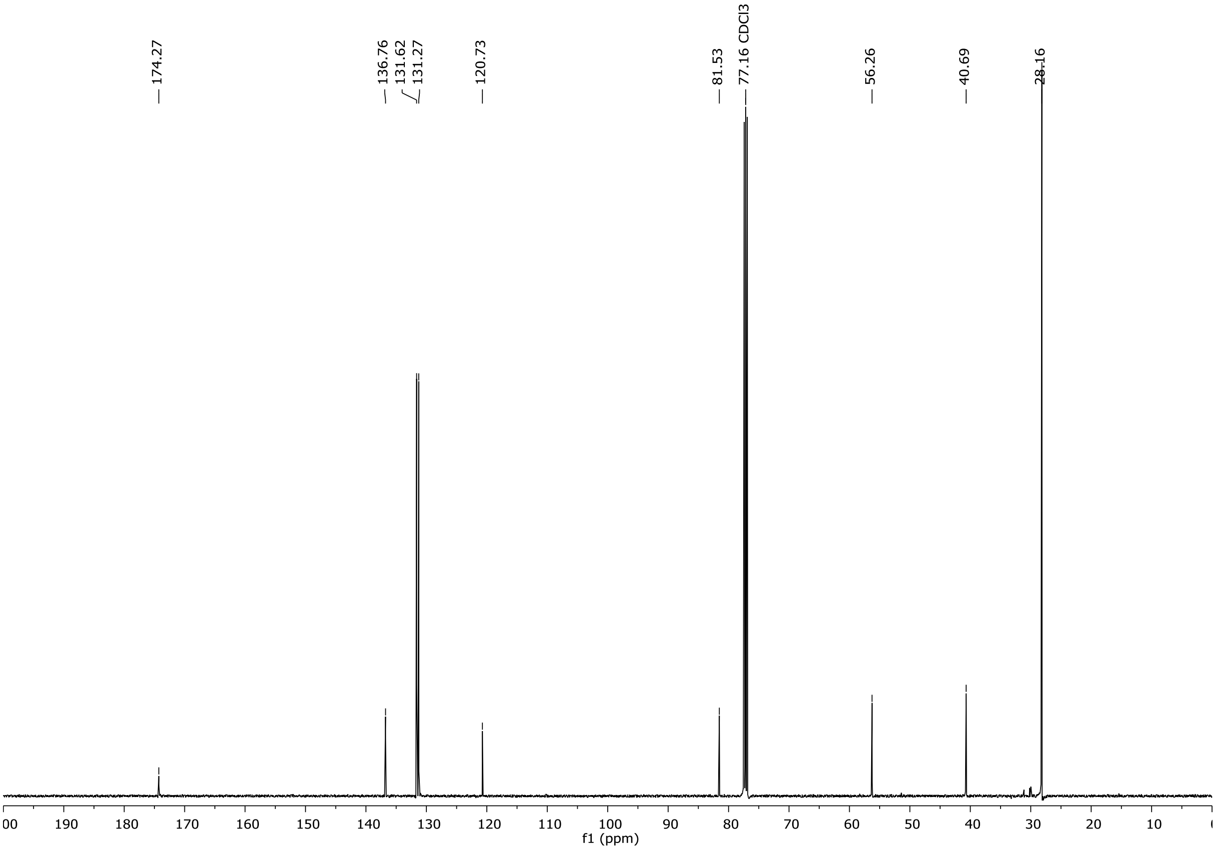


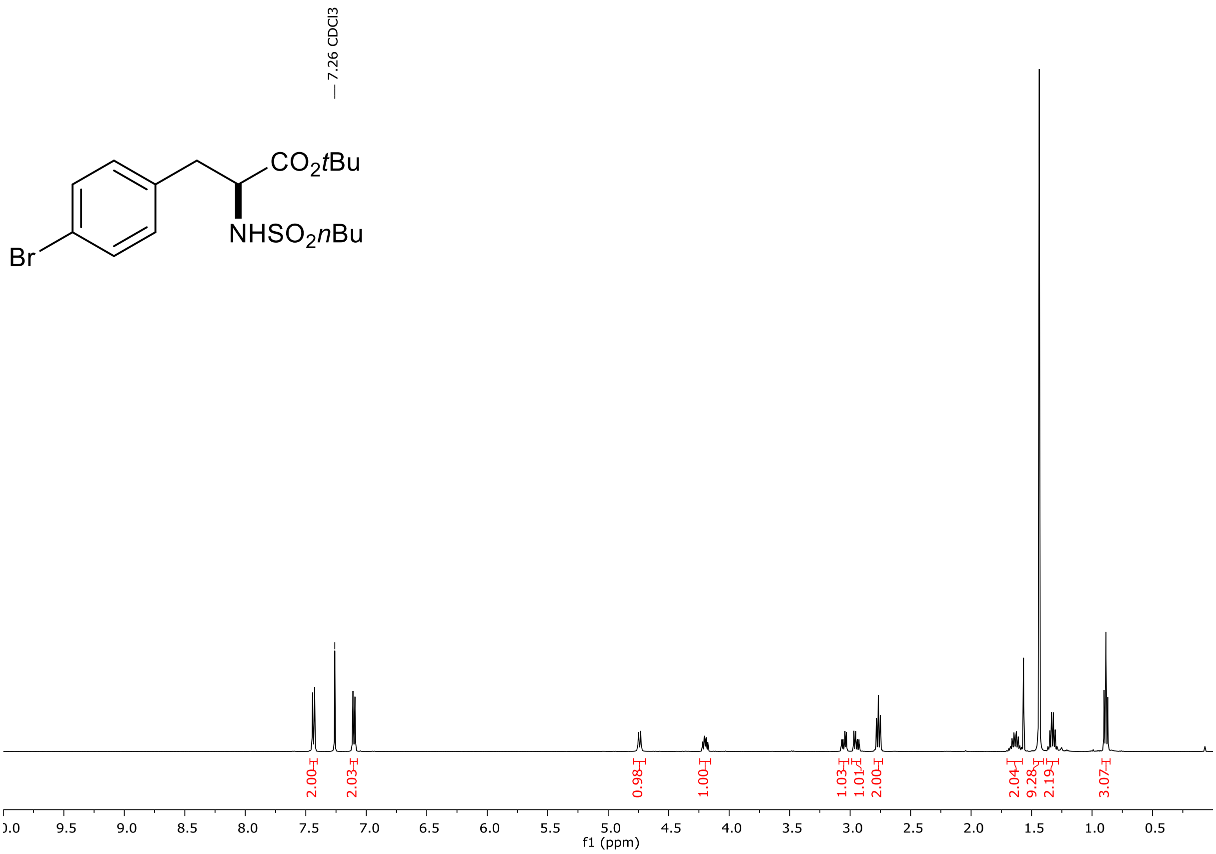
155.07
79.27
77.16 CDCl3
63.28
44.47
43.85
36.45
36.11
33.13
32.32
28.63
26.13
22.98
18.52
-5.10
00
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

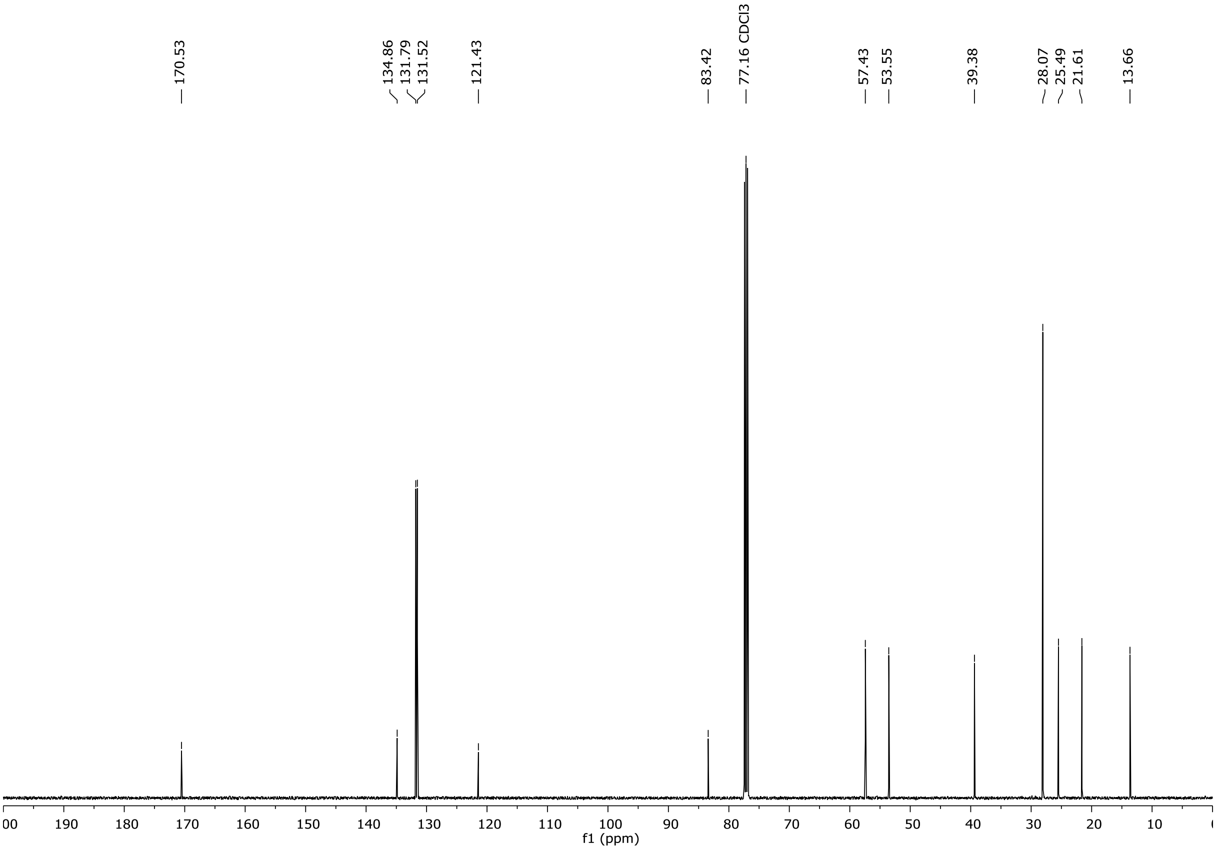

7.26 CDCl3
OH
BocN
2.00
2.03
2.01
2.33
2.62
9.37
3.91
2.82
2.23
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

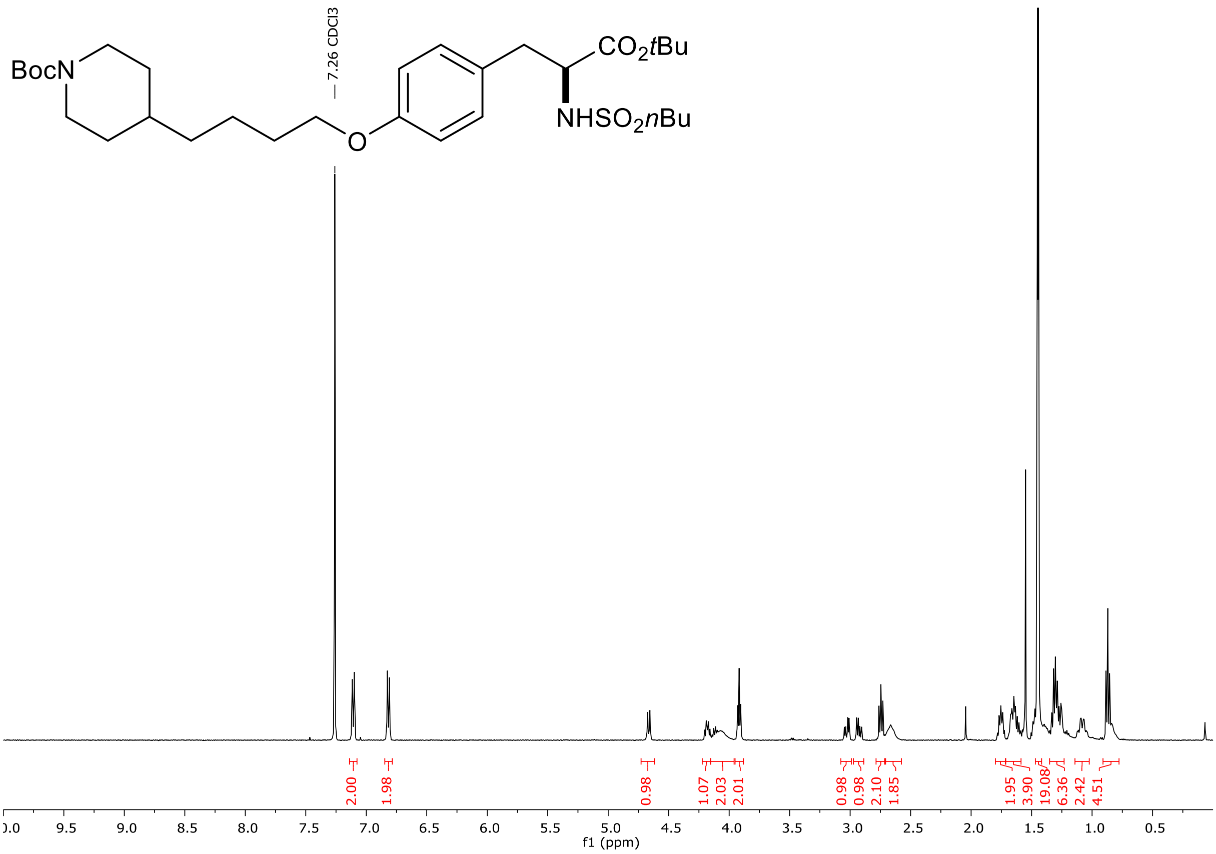

155.06
79.32
77.16 CDCl3
66.01
44.29
36.44
36.12
33.05
32.31
28.63
22.96
15.43
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

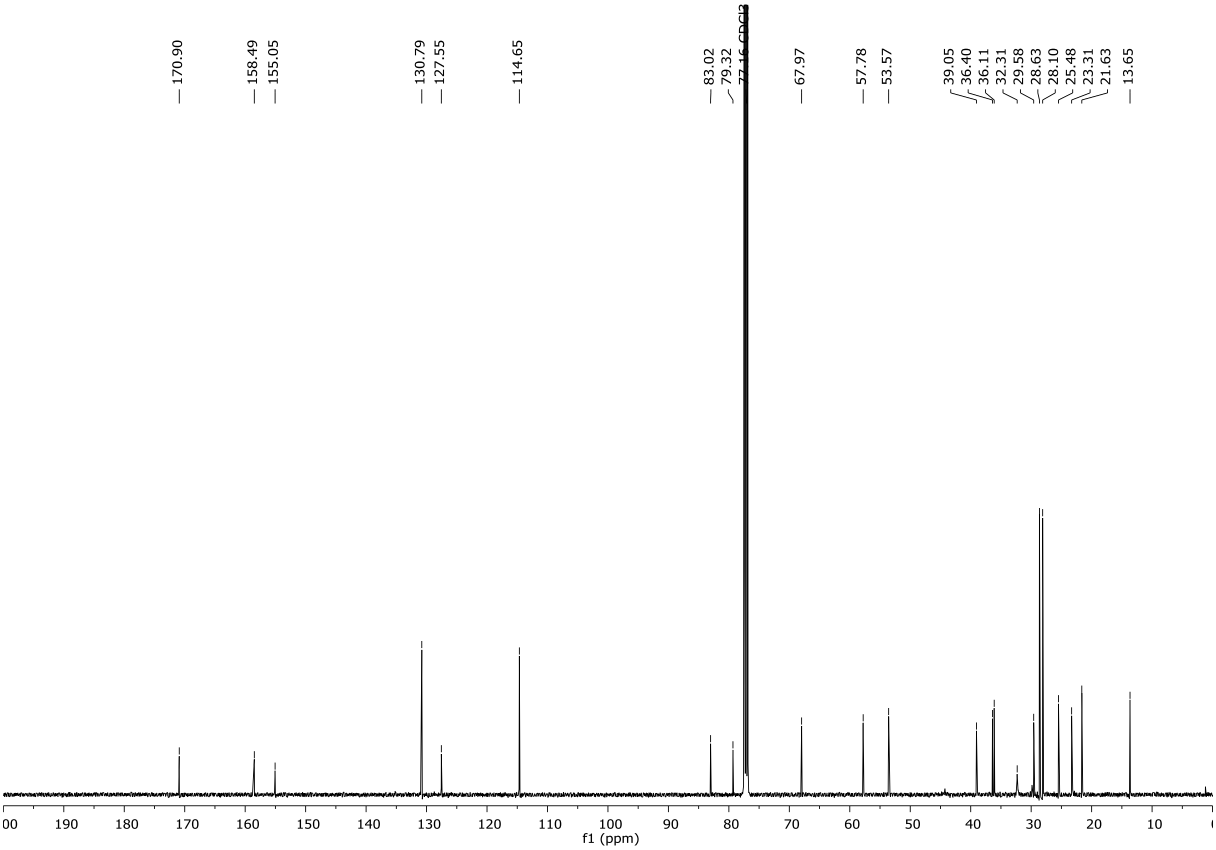

CO2tBu
NH2
Br
7.26 CDCl3
2.00
2.04
0.99
1.02
1.02
9.94
0.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5
f1 (ppm)

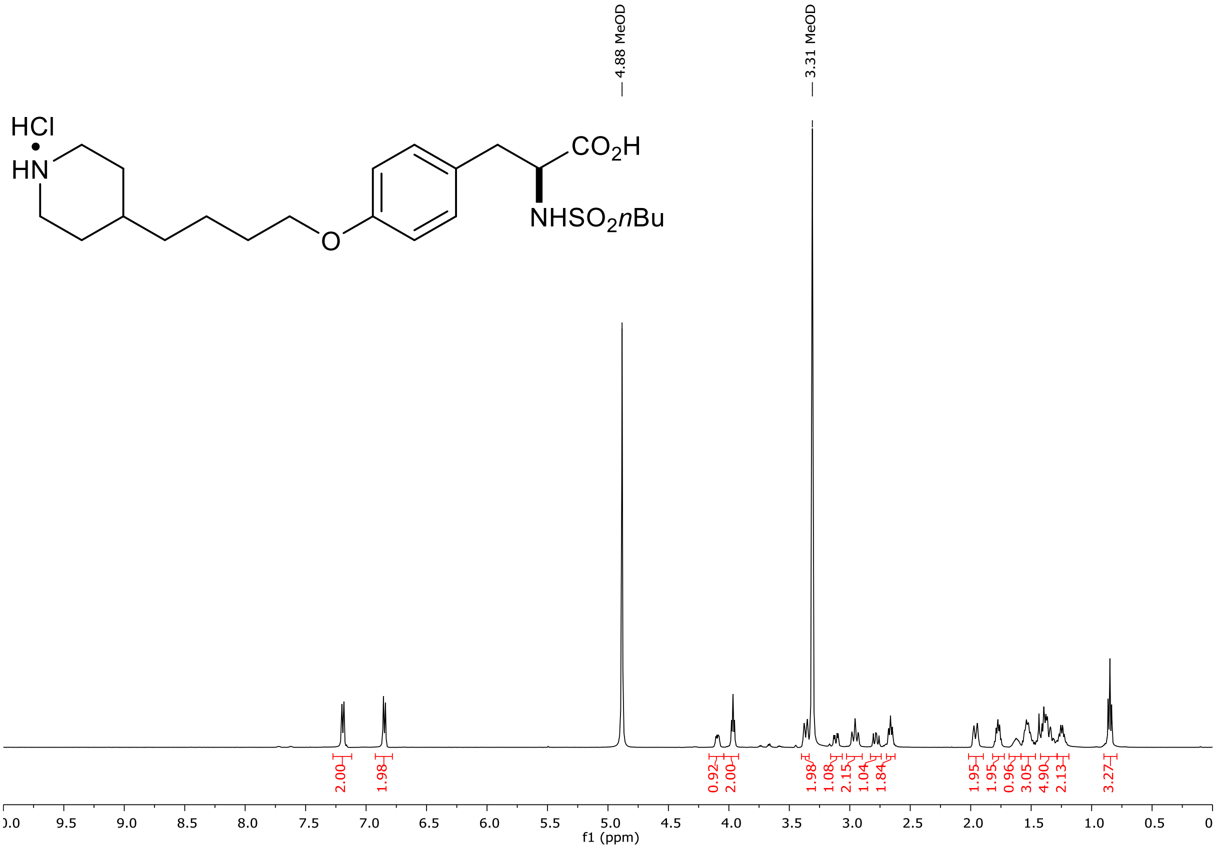

174.27
136.76
131.62
131.27
120.73
81.53
77.16 CDCl3
56.26
40.69
28.16
00 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

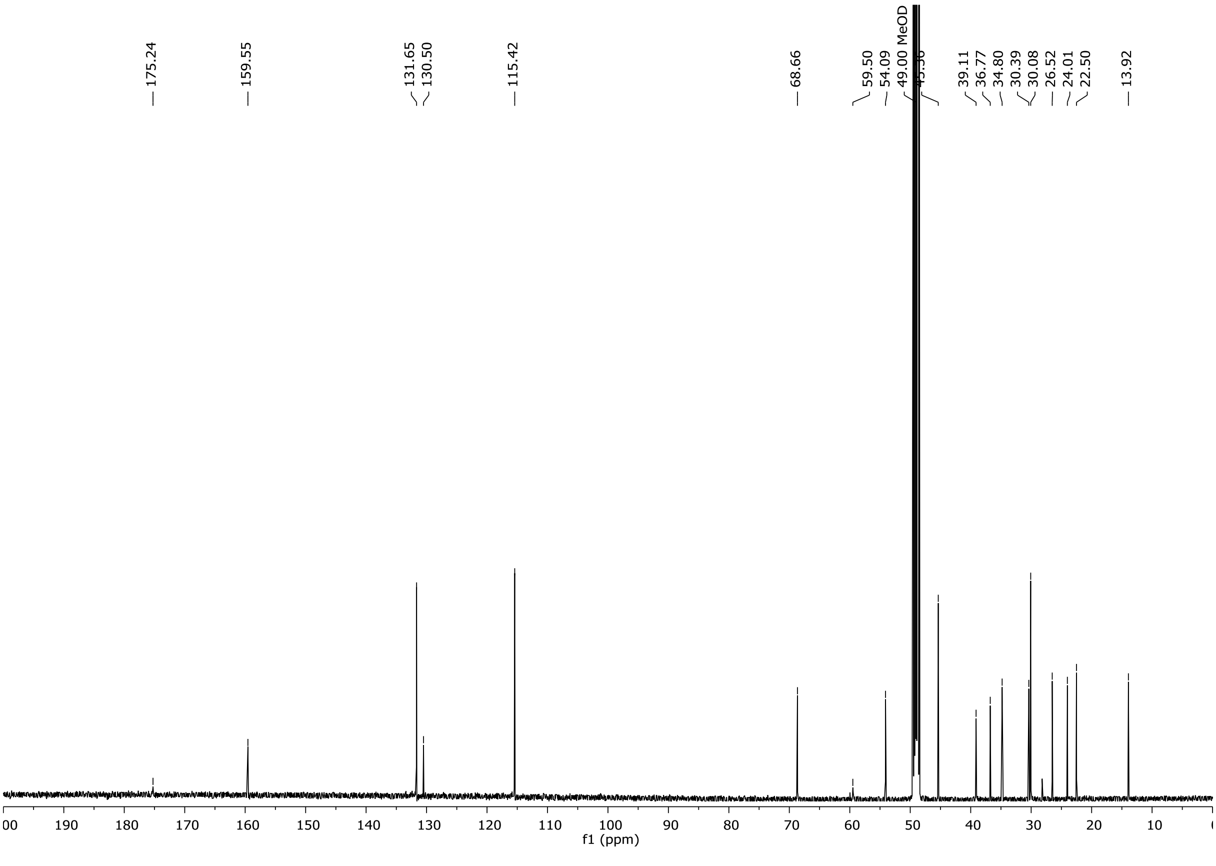

7.26 CDCl3
CO2tBu
NHSO2nBu
Br
2.00
2.03
0.98
1.00
1.03
1.01
2.00
2.04
9.28
2.19
3.07
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

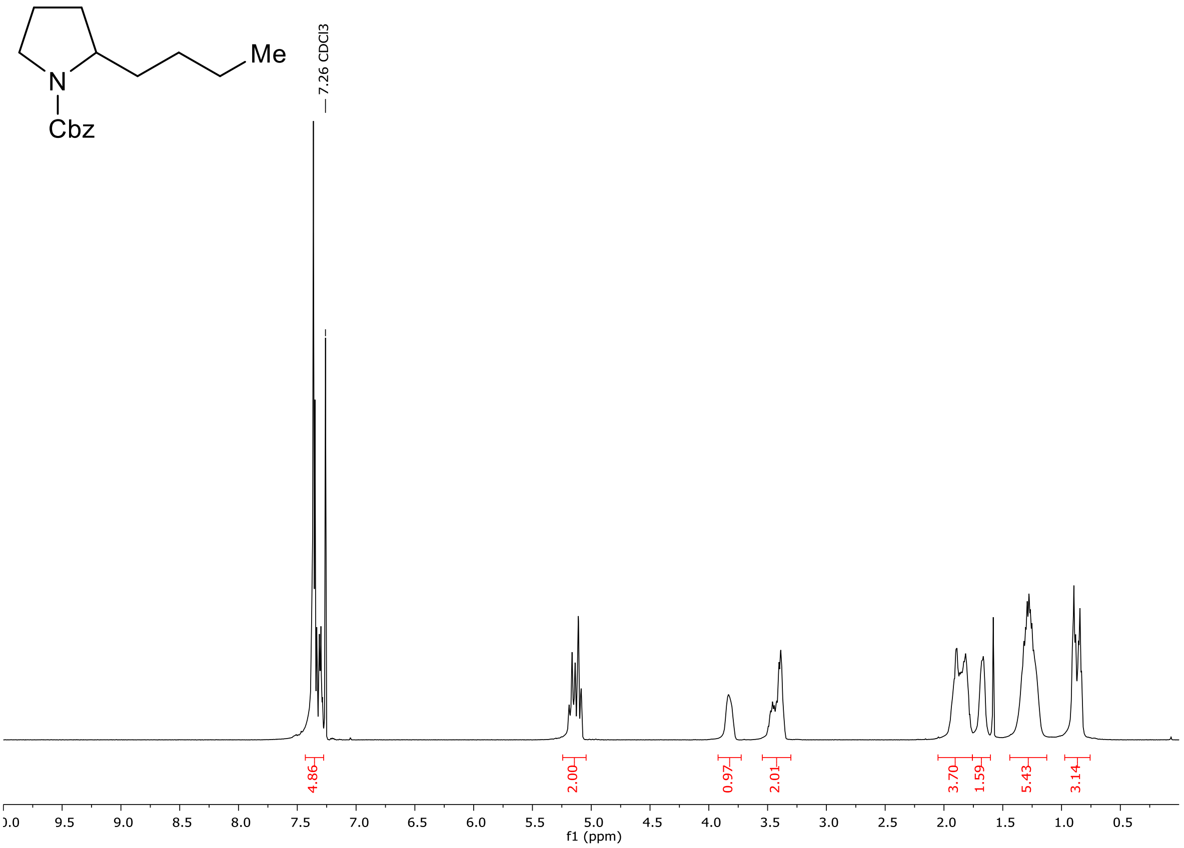

170.53
134.86
131.79
131.52
121.43
83.42
77.16 CDCl3
57.43
53.55
39.38
28.07
25.49
21.61
13.66
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

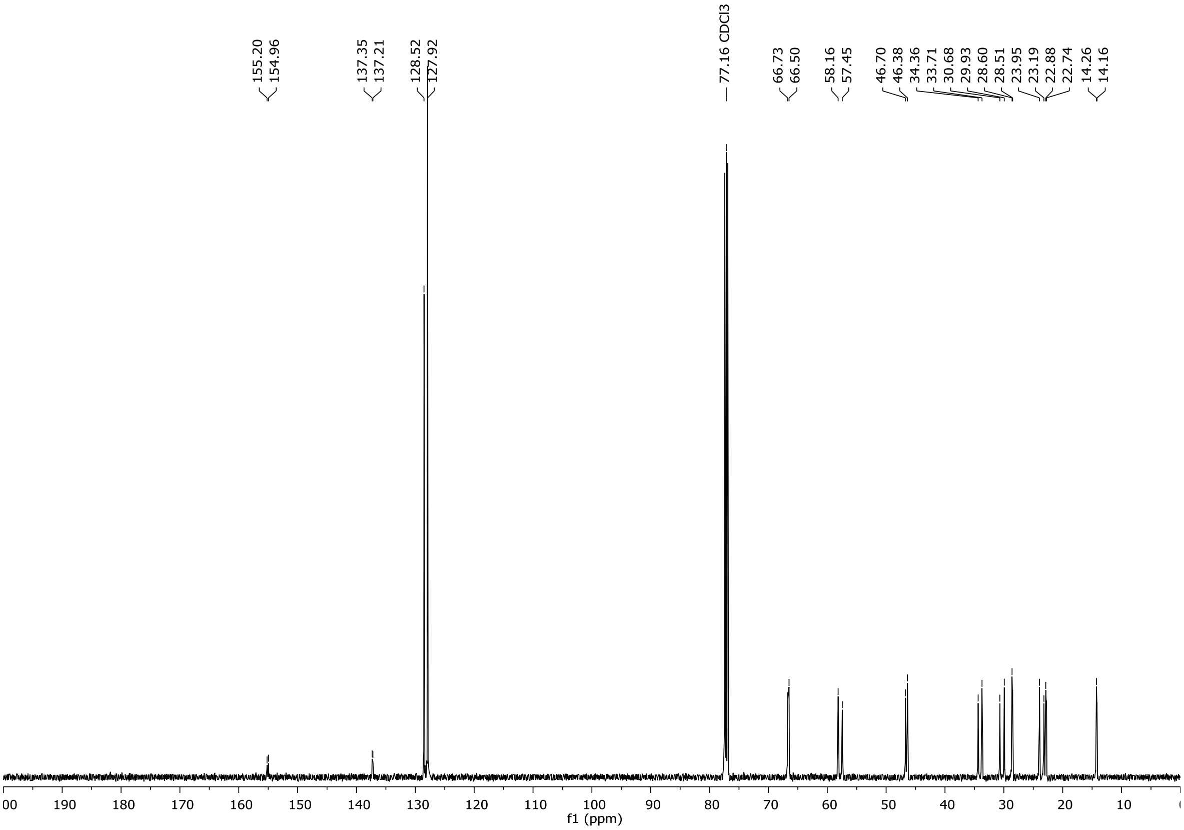

BocN
O
CO2tBu
NHSO2nBu
7.26 CDCl3
2.00
1.98
0.98
1.07
2.03
2.01
0.98
0.98
2.10
1.85
1.95
3.90
19.08
6.36
2.42
4.51
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

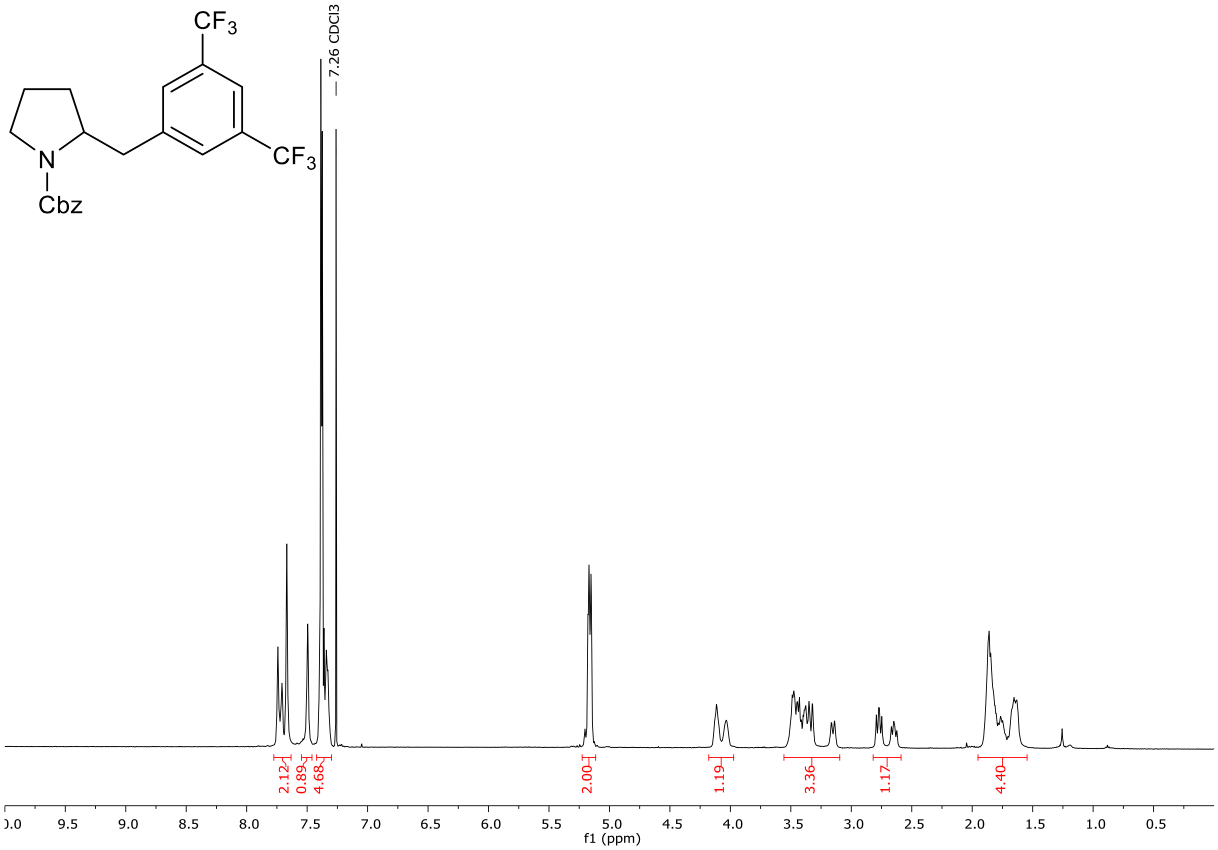

170.90
158.49
155.05
130.79
127.55
114.65
83.02
79.32
77.16 CDCl3
67.97
57.78
53.57
39.05
36.40
36.11
32.31
29.58
28.63
28.10
25.48
23.31
21.63
13.65
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

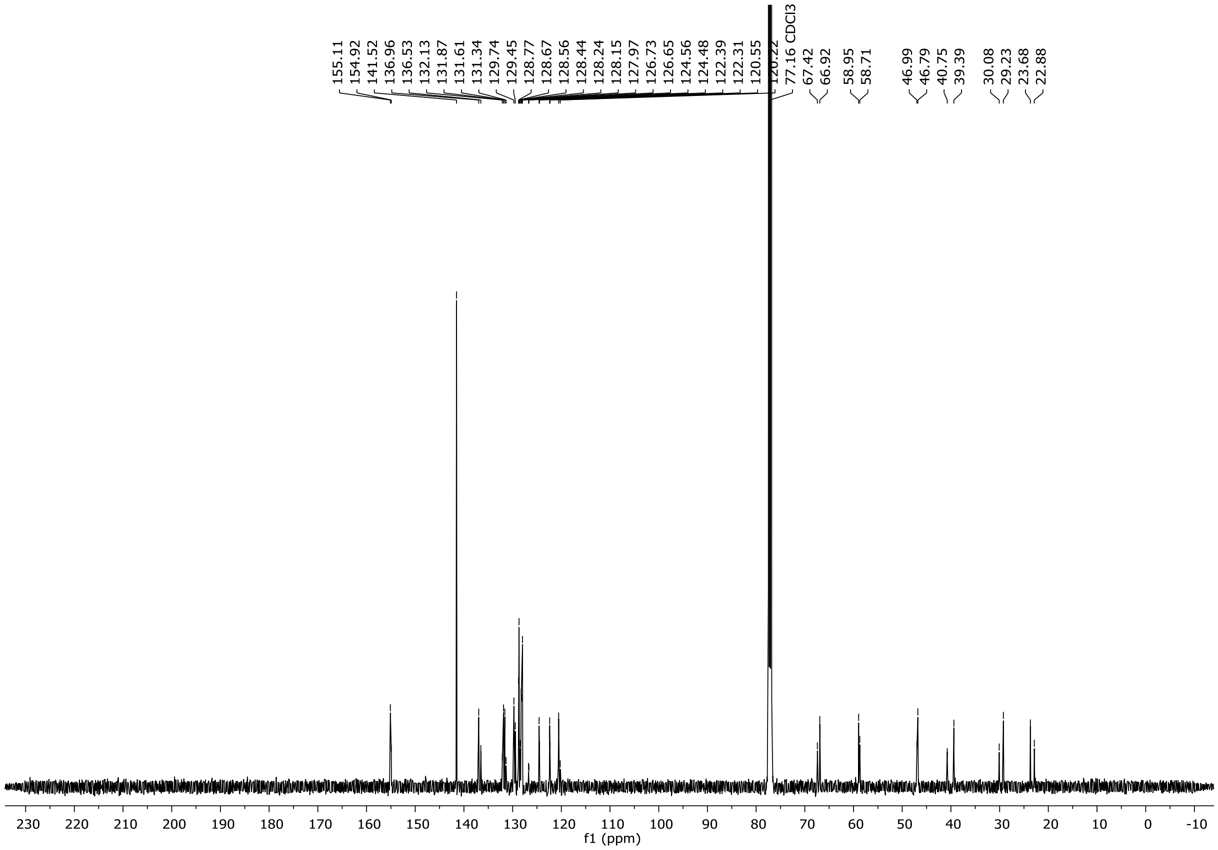

HCl
HN
O
CO2H
NHSO2nBu
4.88 MeOD
3.31 MeOD
2.00
1.98
0.92
2.00
1.98
1.08
2.15
1.04
1.84
1.95
1.95
0.96
3.05
4.90
2.13
3.27
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0
f1 (ppm)

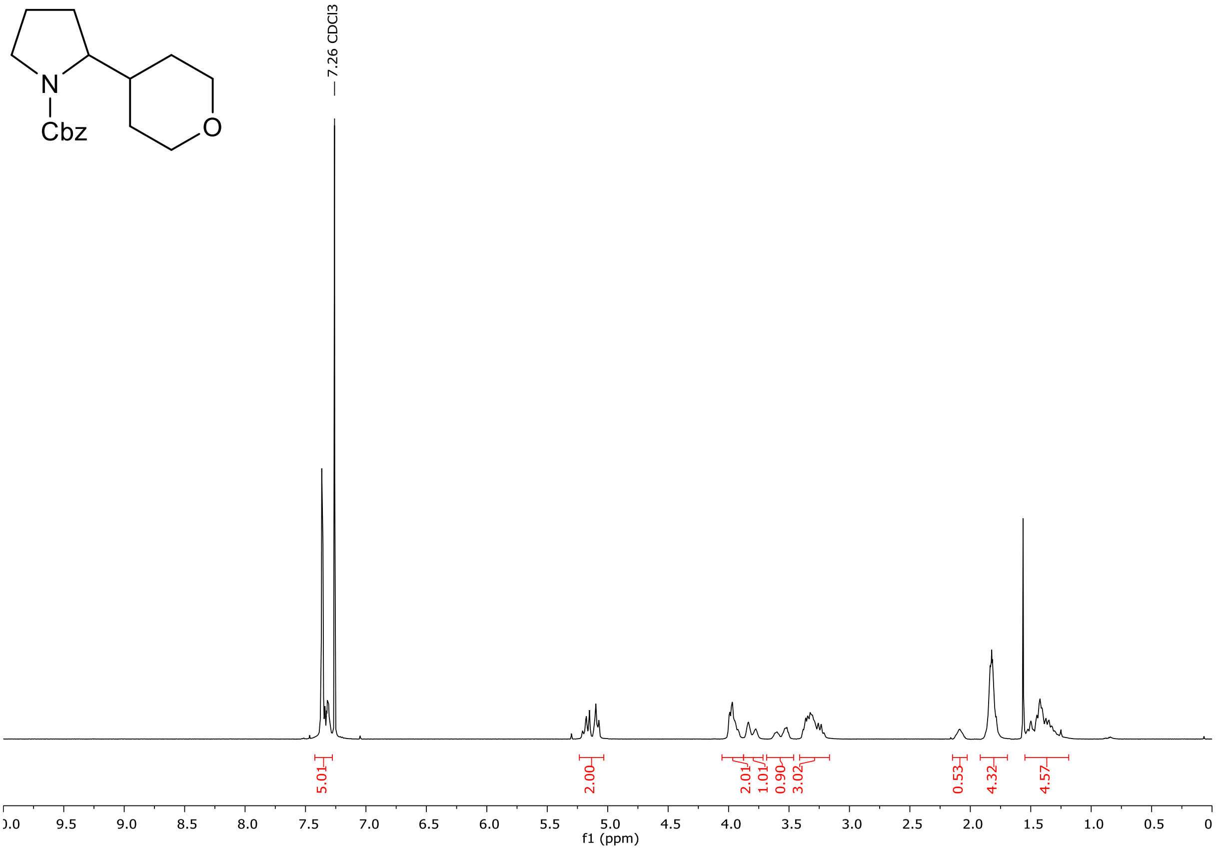

175.24
159.55
131.65
130.50
115.42
68.66
59.50
54.09
49.00 MeOD
45.36
39.11
36.77
34.80
30.39
30.08
26.52
24.01
22.50
13.92
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

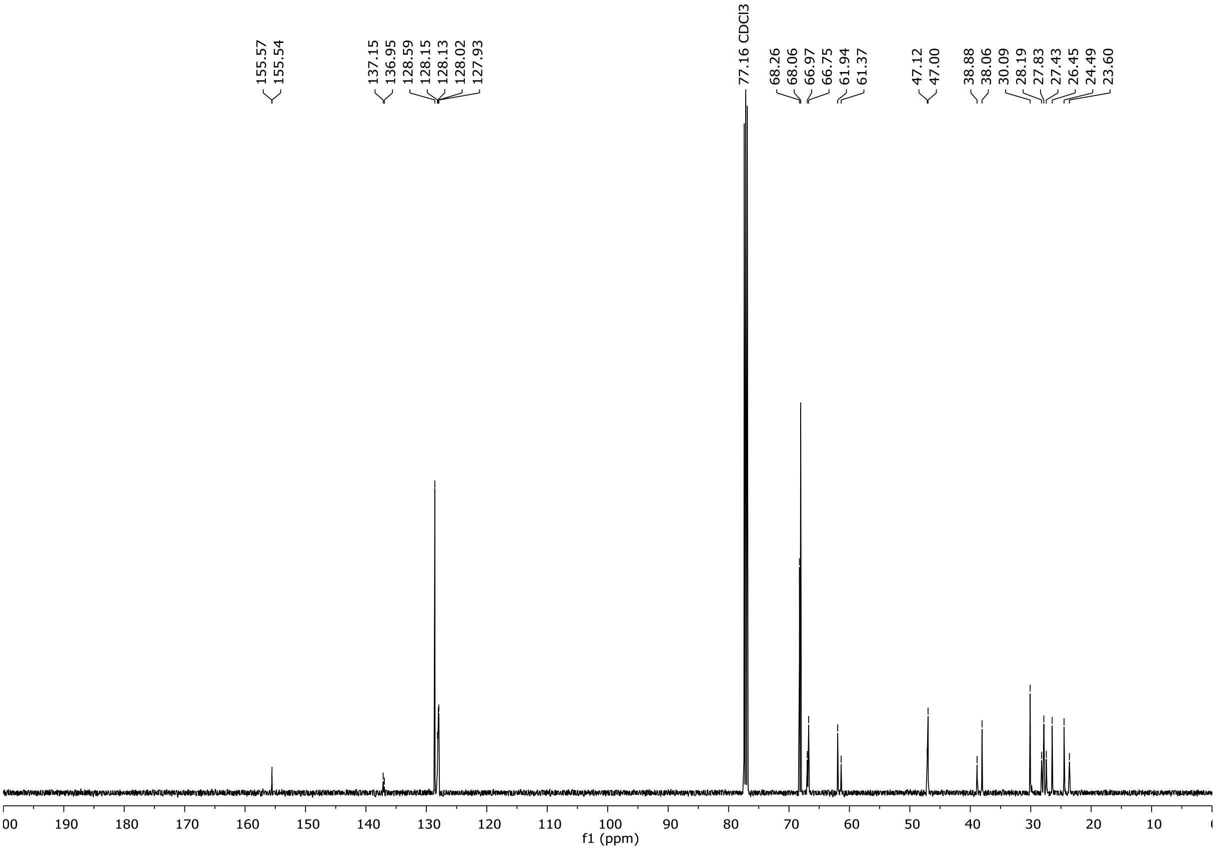

Me
N
Cbz
7.26 CDCl3
4.86
2.00
0.97
2.01
3.70
1.59
5.43
3.14
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

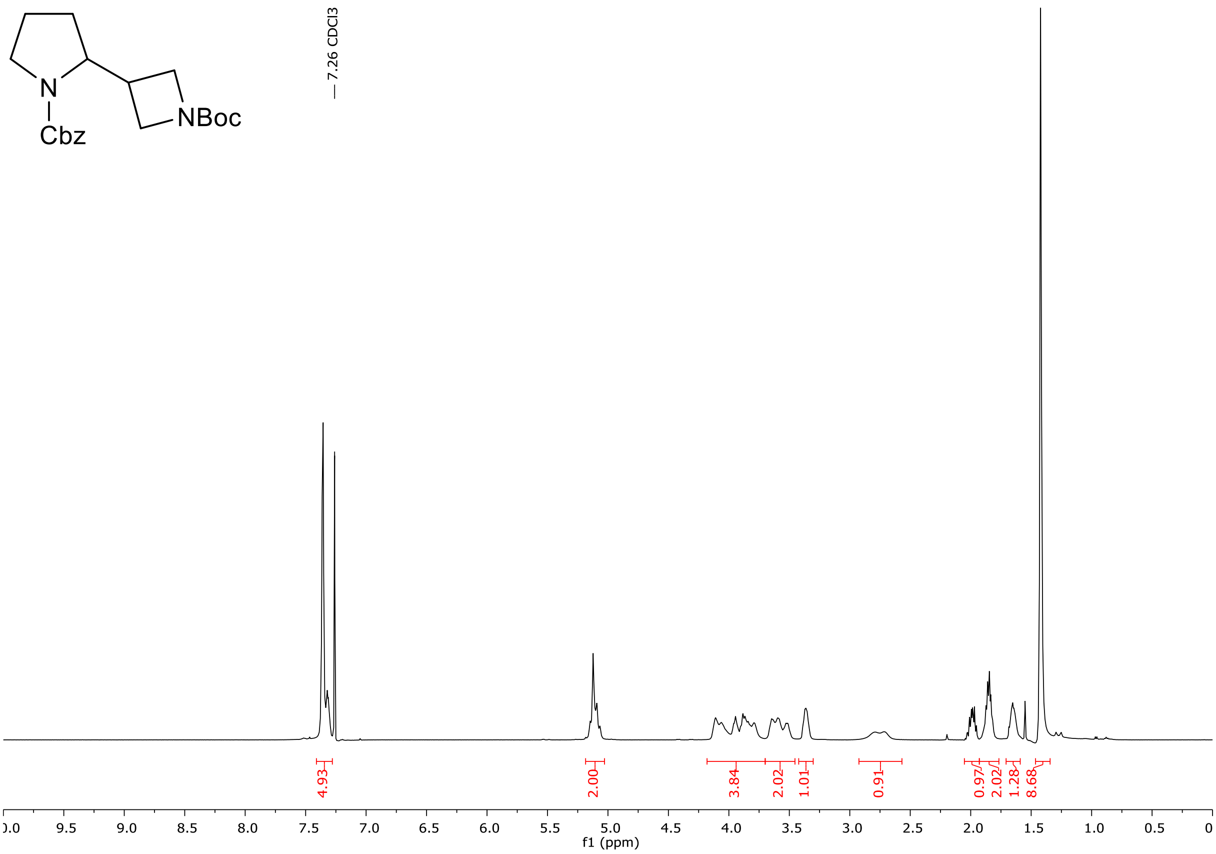

155.20
154.96
137.35
137.21
128.52
127.92
77.16 CDCl3
66.73
66.50
58.16
57.45
46.70
46.38
34.36
33.71
30.68
29.93
28.60
28.51
23.95
23.19
22.88
22.74
14.26
14.16
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

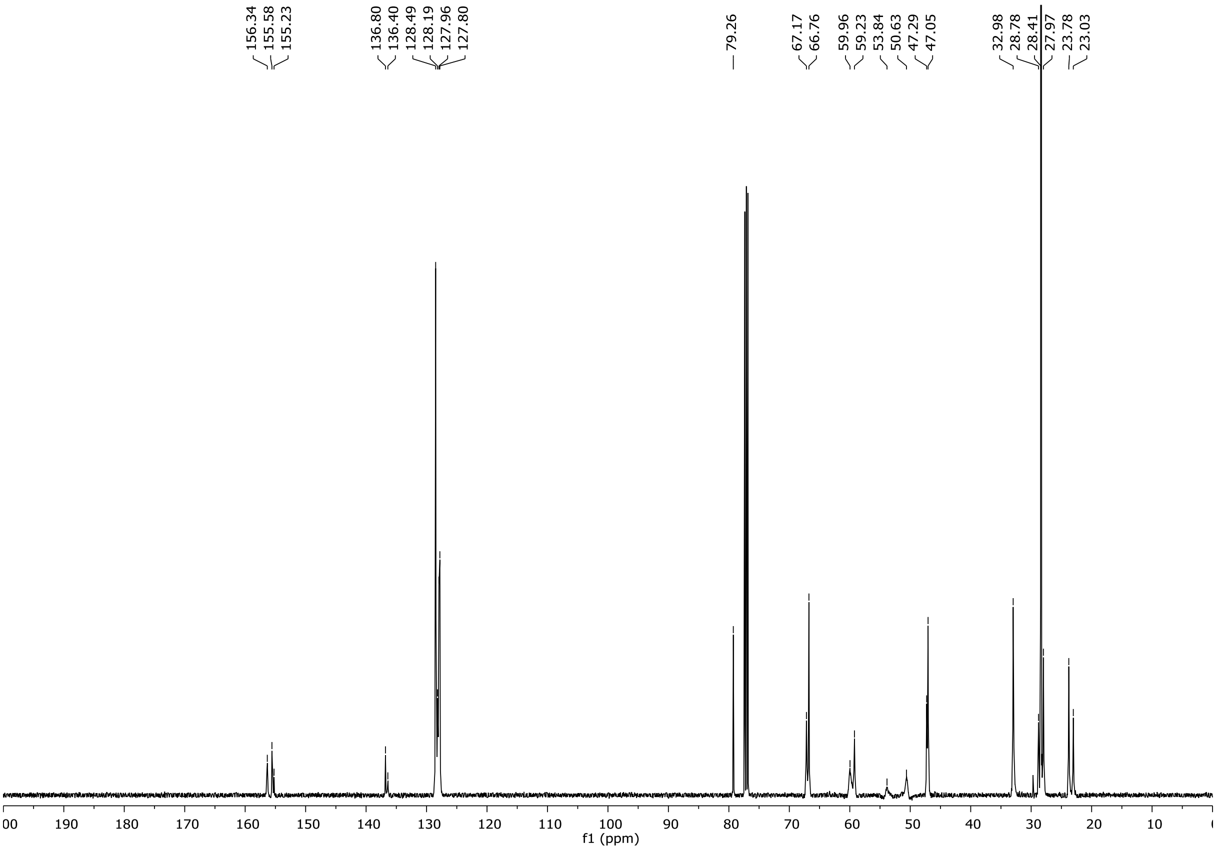

CF3
CF3
N
Cbz
7.26 CDCl3
2.12
0.89
4.68
2.00
1.19
3.36
1.17
4.40
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

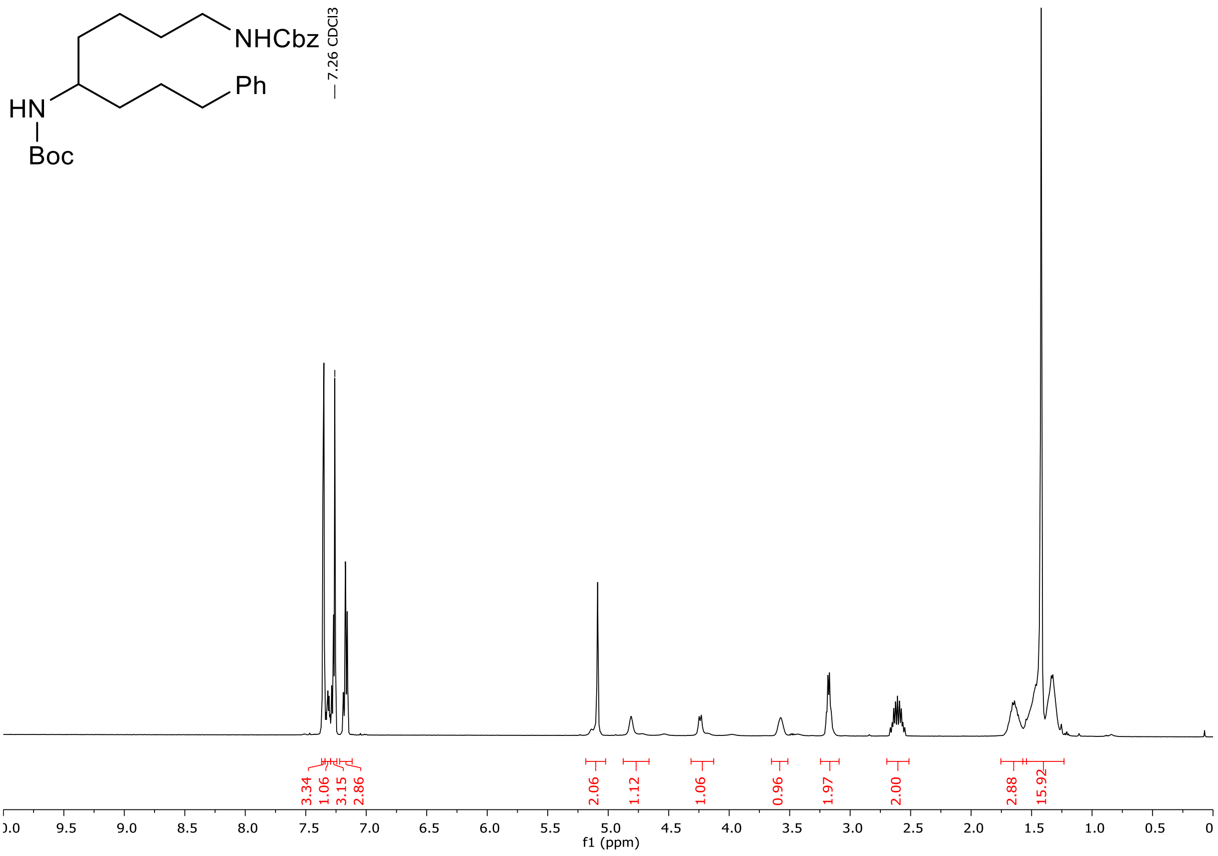

155.11
154.92
141.52
136.96
136.53
132.13
131.87
131.61
131.34
129.74
129.45
128.77
128.67
128.56
128.44
128.24
128.15
127.97
126.73
126.65
124.56
124.48
122.39
122.31
120.55
120.22
77.16 CDCl3
67.42
66.92
58.95
58.71
46.99
46.79
40.75
39.39
30.08
29.23
23.68
22.88
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

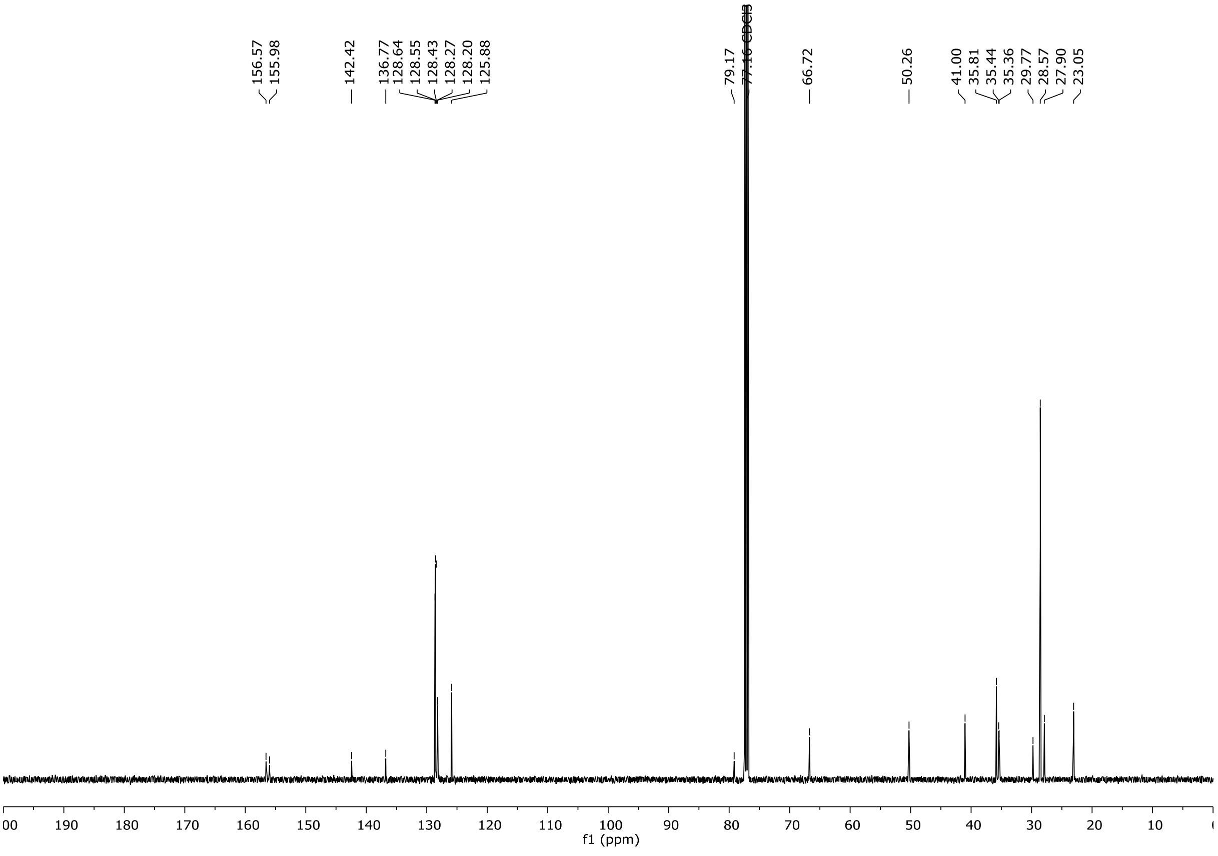

N
Cbz
O
7.26 CDCl3
5.01
2.00
2.01
1.01
0.90
3.02
0.53
4.32
4.57
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
f1 (ppm)


155.57
155.54
137.15
136.95
128.59
128.15
128.13
128.02
127.93
77.16 CDCl3
68.26
68.06
66.97
66.75
61.94
61.37
47.12
47.00
38.88
38.06
30.09
28.19
27.83
27.43
26.45
24.49
23.60
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


N
Cbz
NBoc
7.26 CDCl3
4.93
2.00
3.84
2.02
1.01
0.91
0.97
2.02
1.28
8.68
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
f1 (ppm)


156.34
155.58
155.23
136.80
136.40
128.49
128.19
127.96
127.80
79.26
67.17
66.76
59.96
59.23
53.84
50.63
47.29
47.05
32.98
28.78
28.41
27.97
23.78
23.03
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)


NHCbz
Ph
HN
Boc
7.26 CDCl3
3.34
1.06
3.15
2.86
2.06
1.12
1.06
0.96
1.97
2.00
2.88
15.92
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
f1 (ppm)


156.57
155.98
142.42
136.77
128.64
128.55
128.43
128.27
128.20
125.88
79.17
77.16 CDCl3
66.72
50.26
41.00
35.81
35.44
35.36
29.77
28.57
27.90
23.05
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)