Electronic Supplementary Information

Diversity-Oriented Synthesis of Peptide-Boronic Acids by a Versatile Building-Block Approach

Stefan P. A. Hinkes, Severin Kämmerer and Christian D. P. Klein*
Institute of Pharmacy and Molecular Biotechnology (IPMB), Medicinal Chemistry, Heidelberg University, Im Neuenheimer Feld 364, 69120 Heidelberg.

Table of contents

General information

The following reagents and solvents were used:

Reagent	Indicated Purity	Supplier
Acetonitrile HPLC grade (**ACN**)	≥ 99.9%	VWR Chemicals
1-[Bis(dimethylamino)methylene]-1*H*-1,2,3-triazolo[4,5-b]pyridinium 3-oxide hexafluorophosphate (**HATU**)	99%	Carbolution
Bis(pinacolato)diboron (**B_2pin_2**)	99%	Carbolution
(1-Cyano-2-ethoxy-2-oxoethylidenaminooxy)-dimethylamino-morpholino-carbenium hexafluorophosphate (**COMU**)	98%	Carbolution
Cyclohexane	≥ 99.5%	Honeywell
N,*N'*-Dicyclohexylcarbodiimide (**DCC**)	99%	Merck/Aldrich
Diethanolamine (**DEA**)	98%	Merck/Aldrich
Diethylether (**DEE**), stabilised with BHT	≥ 99.8%	Merck/Aldrich
N,*N'*-Diisopropylcarbodiimide (**DIC**)	98%	Carbolution
4-(Dimethylamino)pyridine (**DMAP**)	≥ 99%	Merck/Aldrich
N,*N*-Dimethylformamide (**DMF**)	≥ 99.8%	Honeywell
N-Ethyldiisopropylamine (**DIPEA**)	99%	Alfa Aesar
Hydrochloric acid (1 N)		Honeywell
N-Hydroxyphthalimide (**NHPI**)	≥ 99%	TCI
Magnesium bromide diethyl etherate	99%	Merck/Aldrich
Methanol HPLC Grade	≥ 99.8%	Fisher Scientific
Methylboronic acid	98%	Carbolution
Methylene chloride (**DCM**)	≥ 99.9%	Merck/Aldrich
Nickel-(II)-chloride hexahydrate	≥ 98%	Honeywell
Piperidine	99%	Merck/Aldrich
Phosphate buffer pH 7.0		Honeywell
Tetrahydrofuran anhydrous (**THF**), stabilised with BHT	≥ 99.5%	TCI
Trifluoroacetic acid (**TFA**)	99%	Alfa Aesar
Triisopropylsilane (**TIPS**)	≥ 98%	TCI
2,4,6-Trimethylpyridine (**TMP**)	99%	Merck/Aldrich

Fmoc-protected amino acids were purchased from Carbolution, Merck/Aldrich, TCI, Alfa Aesar and Orpegen Peptide Chemicals and were used without further purification. Reactions were performed in ambient atmosphere with oven-dried glassware unless otherwise stated. Anhydrous solvents were purchased as such and stored under inert gas and molecular sieves. Ethyl acetate and deionised water were distilled prior to use.

For solid-phase synthesis, polypropylene reaction vessels equipped with polyethylene frits (Carl Roth) were used. Reaction vessels were continuously shaken at ambient temperature using an IKA "KS 130 basic" orbital shaker. 1-Glycerol polystyrene resin (loading capacity: 0.60 mmol/g) was purchased from Iris Biotech.

Reported yields of boronic acids are calculated based on the free acid form without consideration of anhydride formation unless otherwise stated. Depending on the product's tendency to form anhydrides, e.g. boroxines or intramolecular cyclisation products, actual yields are expected to be slightly higher.

Flash column chromatography was done using an "Isolera One" system (Biotage) with silica gel (40 – 63 µm, 60 Å, Material Harvest). Purifications were usually achieved by gradient elution with binary mixtures of cyclohexane and ethyl acetate and UV detection at 254 nm and 280 nm.

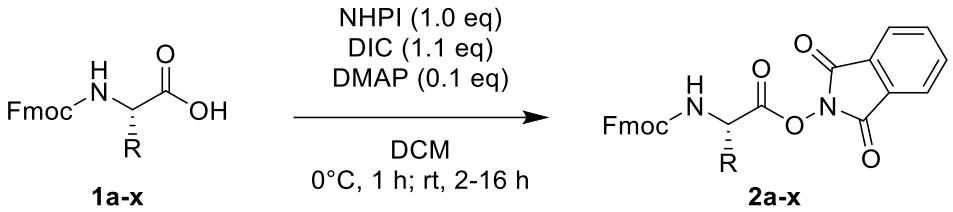
MS-ESI analysis was performed on a Bruker "micrOTOF-Q II" mass spectrometer. For high-resolution mass spectra, sodium formate was used as calibrating reagent. In some cases, a solution of diethanolamine in acetonitrile (10 µL, c = 10 mM) was added to the MS samples of boronic acids to facilitate the formation of cationic species and therefore the detection in positive mode.

NMR spectra were recorded on 300 MHz or 500 MHz Varian instruments. Samples were dissolved in $CDCl_3$, acetone-d_6, DMSO-d_6, CD_3CN, CD_3OD and D_2O or mixtures thereof. To reverse anhydride formation that impedes NMR analysis of boronic acids, small amounts of D_2O were usually added to the samples of boronic acids. Chemical shifts are reported in ppm relative to TMS using the solvent residual peaks of the deuterated species as an internal standard. Solvent residual shifts for ^1H and ^{13}C NMR nuclei were taken from the literature ($CDCl_3$: 7.26 ppm and 77.16 ppm; acetone-d_6: 2.05 ppm and 29.84 ppm; DMSO-d_6: 2.50 ppm and 39.50 ppm; CD_3OD: 3.31 ppm and 49.00 ppm; CD_3CN: 1.94 ppm and 1.32 ppm).[1] Coupling constants are given in Hertz (Hz). Multiplicity is reported as observed, with the following abbreviations used: s (singlet), d (doublet), t (triplet), q (quadruplet), dd (doublet of doublet), dt (doublet of triplet), td (triplet of doublet), m (multiplet). Two-dimensional NMR

experiments (COSY, HSQC, HMBC) were performed in some cases to facilitate assignments, e.g. of diastereomeric mixtures. In proton NMR, acidic protons (e.g. Fmoc-N*H*) were not observed after addition of D_2O due to solvent exchange processes. ^{13}C NMR were measured as "attached proton test" (APT) experiments for facilitated assignments. The carbon attached to boron was not observed due to the quadrupolar relaxation of ^{10}B and ^{11}B nuclei. ^{11}B spectra were measured for representative compounds at 160 MHz using $BF_3 \cdot OEt_2$ as an external standard. Signals of boron nuclei in pinacolyl boronates and free boronic acids were found in the range of 25-35 ppm, regardless of their substitution pattern. Therefore, the respective spectra are not shown.

Final peptides were purified by RP-HPLC, if indicated, using an "ÄKTApurifier" (GE Healthcare, Germany) with a precolumn (Reprospher 100 C18-DE, 5 µm, 30×16 mm, Dr. Maisch, Germany) and a main column (Reprospher 100 C18-DE, 5 µm, 125×16 mm, Dr. Maisch, Germany), Purification was achieved using gradient elution (solvent A: H_2O + 0.1% TFA; solvent B: ACN + 0.1% TFA or MeOH + 0.1% TFA) with UV detection at 214, 254 and 280 nm. Product-containing fractions were lyophilised with an "Alpha 1-2 LDplus" freeze-drier (Martin Christ, Germany).

Synthesis of *N*-hydroxyphthalimide (NHPI) esters



General procedure

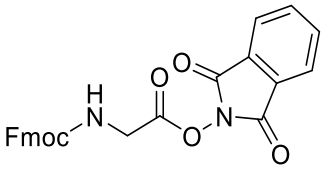
NHPI esters were prepared by a literature-known method with slight modifications.[1]

A round-bottom flask was charged with the respective Fmoc-protected amino acid (**1**, 1.0 eq), *N*-hydroxyphthalimide (NHPI, 1.0 eq) and *N*,*N*-dimethylaminopyridine (DMAP, 0.1 eq) were added. After the addition of methylene chloride (~ 5 mL/mmol), the mixture was cooled to 0°C and *N*,*N*'-diisopropylcarbodiimide (DIC, 1.1 eq) was added dropwise. The reaction was stirred for 1 h at 0°C, allowed to warm up to ambient temperature and stirred for 2-16 hours. The resulting precipitate was filtered and washed with additional methylene chloride. The filtrate was concentrated *in vacuo* and purified by flash chromatography using silica and cyclohexane/ethyl acetate gradients.

NOTE: Nucleophilic solvents, e. g. alcohols, should be avoided for NMR and MS analysis due to the enhanced reactivity of the activated esters. MS samples were therefore prepared using acetonitrile, NMR samples were prepared using $CDCl_3$ or CD_3CN.

N-hydroxyphthalimide (NHPI) esters

Fmoc-Gly-ONHPI (2a)



On 1.0 mmol scale, Fmoc-Gly-ONHPI (**2a**) was obtained as a colorless foam (363.2 mg, 0.821 mmol, 82%).

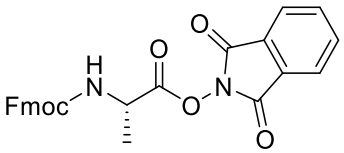
The spectroscopic data is consistent with the literature.[2]

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.95 – 7.85 (m, 2H), 7.84 – 7.78 (m, 2H), 7.76 (d, *J* = 7.6 Hz, 2H), 7.59 (d, *J* = 7.4 Hz, 2H), 7.40 (t, *J* = 7.3 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.34 (t, *J* = 5.6 Hz, 1H), 4.53 – 4.32 (m, 4H), 4.24 (t, *J* = 7.1 Hz, 1H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 167.0, 161.5, 156.1, 143.8, 141.4, 135.1, 128.9, 127.9, 127.2, 125.2, 124.3, 120.1, 67.7, 47.2, 40.8 ppm.

HRMS (ESI, m/z): Calcd for $C_{25}H_{18}N_2O_6Na$ $[M + Na]^+$ 465.1057; found 465.1061.

Fmoc-Ala-ONHPI (2b)



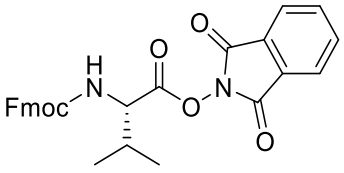
On 1.0 mmol scale, Fmoc-Ala-ONHPI (**2b**) was obtained as a colorless solid (375.6 mg, 0.82 mmol, 82%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.94 – 7.85 (m, 2H), 7.84 – 7.72 (m, 4H), 7.61 (d, *J* = 7.5 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.3 Hz, 2H), 5.31 (d, *J* = 8.9 Hz, 1H), 4.94 – 4.75 (m, 1H), 4.55 – 4.34 (m, 2H), 4.25 (t, *J* = 6.7 Hz, 1H), 1.68 (d, *J* = 7.3 Hz, 3H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.8, 161.6, 155.5, 143.9, 143.7, 141.4, 135.0, 128.9, 127.8, 127.2, 125.2, 124.2, 120.1, 67.4, 48.3, 47.2, 18.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{26}H_{20}N_2O_6Na$ $[M + Na]^+$ 479.1214; found 479.1205.

Fmoc-Val-ONHPI (2c)



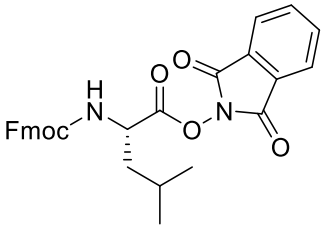
On 1.0 mmol scale, Fmoc-Val-ONHPI (**2c**) was obtained as a colorless solid (439.0 mg, 0.906 mmol, 91%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.94 – 7.84 (m, 2H), 7.84 – 7.73 (m, 4H), 7.61 (d, *J* = 7.3 Hz, 2H), 7.40 (t, *J* = 7.3 Hz, 2H), 7.32 (t, *J* = 7.3 Hz, 2H), 5.33 (d, *J* = 9.5 Hz, 1H), 4.76 (dd, *J* = 9.3, 4.7 Hz, 1H), 4.47 (d, *J* = 6.7 Hz, 2H), 4.25 (t, *J* = 7.1 Hz, 1H), 2.51 – 2.30 (m, 1H), 1.19 – 1.00 (m, 6H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.8, 161.6, 156.0, 144.0, 143.7, 141.4, 135.0, 128.9, 127.9, 127.2, 125.2, 124.2, 120.1, 67.4, 57.7, 47.3, 31.9, 18.9, 17.5 ppm.

HRMS (ESI, m/z): Calcd for $C_{28}H_{24}N_2O_6Na$ $[M + Na]^+$ 507.1527; found 507.1538.

Fmoc-Leu-ONHPI (2d)



On 1.0 mmol scale, Fmoc-Leu-ONHPI (**2d**) was obtained as a colorless foam (439.7 mg, 0.882 mmol, 88%).

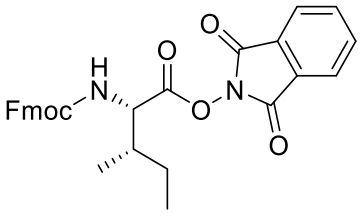
The spectroscopic data is consistent with the literature.[3]

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.93 – 7.84 (m, 2H), 7.83 – 7.72 (m, 4H), 7.61 (d, *J* = 7.2 Hz, 2H), 7.40 (t, *J* = 7.3 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.20 (d, *J* = 8.7 Hz, 1H), 4.90 – 4.77 (m, 1H), 4.47 (d, *J* = 6.7 Hz, 2H), 4.25 (t, *J* = 6.6 Hz, 1H), 1.98 – 1.82 (m, 2H), 1.82 – 1.69 (m, 1H), 1.03 (d, *J* = 5.7 Hz, 6H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.8, 161.6, 155.7, 144.0, 143.7, 141.5, 135.0, 129.0, 127.8, 127.2, 125.2, 124.2, 120.1, 67.4, 51.1, 47.3, 41.9, 24.9, 23.0, 21.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{29}H_{26}N_2O_6Na$ $[M + Na]^+$ 521.1683; found 521.1684.

Fmoc-Ile-ONHPI (2e)



On 1.0 mmol scale, Fmoc-Ile-ONHPI (**2e**) was obtained as a colorless oil (463.5 mg, 0.930 mmol, 93%).

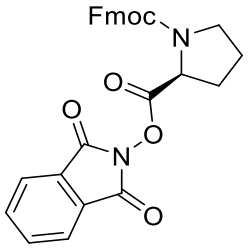
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.89 – 7.80 (m, 2H), 7.79 – 7.68 (m, 4H), 7.61 (d, *J* = 7.0 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.3 Hz, 2H), 5.62 – 5.41 (m, 1H), 4.81 (dd, *J* = 9.1,

5.1 Hz, 1H), 4.46 (d, *J* = 6.8 Hz, 2H), 4.23 (t, *J* = 6.3 Hz, 1H), 2.21 – 2.00 (m, 1H), 1.77 – 1.59 (m, 1H), 1.41 – 1.27 (m, 1H), 1.12 (d, *J* = 6.8 Hz, 3H), 1.04 (t, *J* = 7.4 Hz, 3H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.7, 161.5, 155.9, 143.9, 143.6, 141.3, 134.9, 128.8, 127.8, 127.2, 125.1, 124.0, 120.0, 67.3, 57.1, 47.2, 38.3, 24.9, 15.2, 11.6 ppm.

HRMS (ESI, m/z): Calcd for $C_{29}H_{26}N_2O_6Na$ $[M + Na]^+$ 521.1683; found 521.1684.

Fmoc-Pro-ONHPI (2f)



On 1.0 mmol scale, Fmoc-Pro-ONHPI (**2f**) was obtained as a colorless foam (437.8 mg, 0.907 mmol, 91%) as a mixture of rotamers.

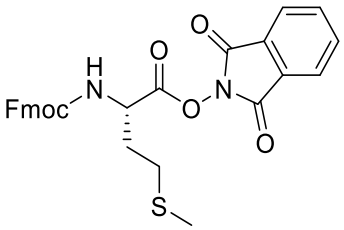
The spectroscopic data is consistent with the literature.[3]

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 – 7.56 (m, 8H), 7.46 – 7.27 (m, 4H), 4.89 – 4.76 (m, 1H), 4.71 – 4.34 (m, 2H), 4.32 – 4.17 (m, 1H), 3.81 – 3.65 (m, 1H), 3.65 – 3.47 (m, 1H), 2.62 – 2.32 (m, 2H), 2.24 – 1.95 (m, 2H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.4, 169.1, 161.5, 154.5, 154.0, 144.7, 143.9, 143.7, 143.5, 141.2, 141.2, 141.1, 141.1, 134.7, 134.7, 128.7, 128.6, 127.6, 127.5, 127.1, 127.0, 125.5, 125.1, 125.0, 123.8, 119.9, 119.8, 68.4, 67.6, 57.3, 57.2, 47.1, 46.9, 46.4, 31.4, 30.2, 24.4, 23.5 ppm.

HRMS (ESI, m/z): Calcd for $C_{28}H_{22}N_2O_6Na$ $[M + Na]^+$ 505.1370; found 505.1365.

Fmoc-Met-ONHPI (2g)



On 1.0 mmol scale, Fmoc-Met-ONHPI (**2g**) was obtained as a colorless solid (429.8 mg, 0.832 mmol, 83%).

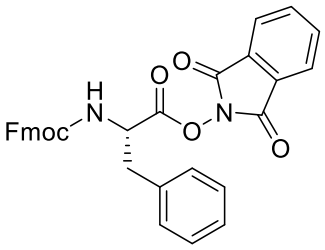
The spectroscopic data is consistent with the literature.[3]

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.88 – 7.79 (m, 2H), 7.79 – 7.69 (m, 4H), 7.65 – 7.53 (m, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.33 – 7.23 (m, 2H), 5.79 (d, *J* = 8.4 Hz, 1H), 5.01 (q, *J* = 7.7 Hz, 1H), 4.45 (d, *J* = 6.8 Hz, 2H), 4.21 (t, *J* = 6.6 Hz, 1H), 2.79 – 2.59 (m, 2H), 2.44 – 2.17 (m, 2H), 2.14 (s, 3H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.9, 161.4, 155.6, 143.8, 143.5, 141.2, 134.9, 128.7, 127.7, 127.1, 125.0, 124.0, 119.9, 67.2, 51.7, 47.1, 31.9, 29.5, 15.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{28}H_{24}N_2O_6SNa$ $[M + Na]^+$ 539.1247; found 539.1237.

Fmoc-Phe-ONHPI (2h)



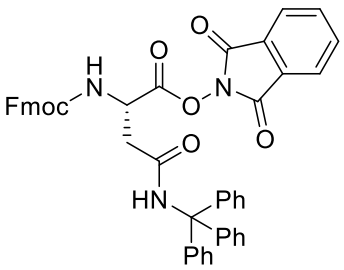
On 1.0 mmol scale, Fmoc-Phe-ONHPI (**2h**) was obtained as a colorless solid (414.1 mg, 0.778 mmol, 78%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.95 – 7.85 (m, 2H), 7.85 – 7.71 (m, 4H), 7.56 (t, *J* = 6.6 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.37 – 7.26 (m, 7H), 5.27 – 5.08 (m, 2H), 4.53 – 4.33 (m, 2H), 4.21 (t, *J* = 6.8 Hz, 1H), 3.43 – 3.25 (m, 2H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.5, 161.5, 155.4, 143.9, 143.7, 141.4, 135.0, 134.5, 129.9, 128.9, 128.9, 127.9, 127.7, 127.2, 125.22, 125.17, 124.2, 120.1, 67.4, 53.1, 47.2, 38.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{32}H_{24}N_2O_6Na$ $[M + Na]^+$ 555.1527; found 555.1520.

Fmoc-Asn(Trt)-ONHPI (2i)



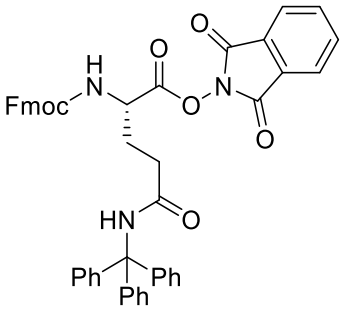
On 1.0 mmol scale, Fmoc-Asn(Trt)-ONHPI (**2i**) was obtained as a colorless solid (591.8 mg, 0.798 mmol, 80%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.88 – 7.80 (m, 2H), 7.80 – 7.70 (m, 4H), 7.63 – 7.54 (m, 2H), 7.38 (t, *J* = 7.3 Hz, 2H), 7.33 – 7.15 (m, 17H), 7.08 (s, 1H), 6.51 (d, *J* = 8.2 Hz, 1H), 5.04 (dt, *J* = 9.1, 5.0 Hz, 1H), 4.45 – 4.26 (m, 2H), 4.20 (t, *J* = 7.3 Hz, 1H), 3.29 – 2.90 (m, 2H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.3, 168.2, 161.4, 156.0, 144.3, 143.9, 143.8, 141.3, 134.9, 128.9, 128.9, 128.1, 127.7, 127.2, 125.4, 125.3, 124.1, 120.0, 71.3, 67.6, 49.8, 47.1, 38.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{46}H_{35}N_3O_7Na$ $[M + Na]^+$ 764.2367; found 764.2330.

Fmoc-Gln(Trt)-ONHPI (2j)



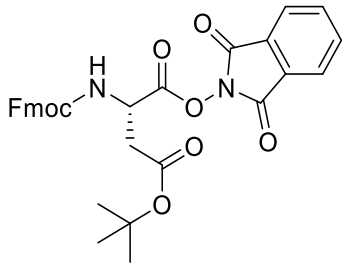
On 1.0 mmol scale, Fmoc-Gln(Trt)-ONHPI (**2j**) was obtained as a colorless solid (610.0 mg, 0.807 mmol, 81%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.91 – 7.83 (m, 2H), 7.83 – 7.77 (m, 2H), 7.74 (d, *J* = 7.4 Hz, 2H), 7.58 (d, *J* = 7.3 Hz, 2H), 7.38 (t, *J* = 7.4 Hz, 2H), 7.33 – 7.17 (m, 17H), 7.03 (s, 1H), 5.88 (d, *J* = 7.5 Hz, 1H), 4.86 – 4.71 (m, 1H), 4.51 – 4.30 (m, 2H), 4.23 (t, *J* = 6.8 Hz, 1H), 2.72 – 2.47 (m, 2H), 2.46 – 2.17 (m, 2H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 170.9, 169.0, 161.7, 155.9, 144.6, 144.0, 143.8, 141.4, 135.0, 128.9, 128.8, 128.1, 127.8, 127.3, 127.2, 125.4, 125.3, 124.2, 120.0, 70.9, 67.4, 52.4, 47.3, 32.8, 27.6 ppm.

HRMS (ESI, m/z): Calcd for $C_{47}H_{37}N_3O_7Na$ $[M + Na]^+$ 778.2524; found 778.2518.

Fmoc-Asp(tBu)-ONHPI (2k)



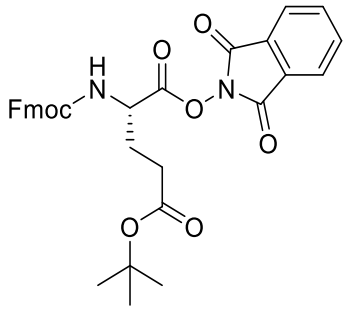
On 1.0 mmol scale, Fmoc-Asp(tBu)-ONHPI (**2k**) was obtained as a pale yellow oil (499.2 mg, 0.897 mmol, 90%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.93 – 7.86 (m, 2H), 7.83 – 7.72 (m, 4H), 7.64 – 7.56 (m, 2H), 7.39 (t, *J* = 7.3 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.99 (d, *J* = 9.4 Hz, 1H), 5.10 (dt, *J* = 9.4, 4.7 Hz, 1H), 4.54 – 4.32 (m, 2H), 4.26 (t, *J* = 7.2 Hz, 1H), 3.21 – 2.85 (m, 2H), 1.52 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.3, 167.9, 161.4, 155.8, 143.9, 143.7, 141.4, 135.0, 129.0, 127.9, 127.2, 125.3, 125.3, 124.2, 120.1, 82.9, 67.7, 49.3, 47.2, 37.9, 28.2 ppm.

HRMS (ESI, m/z): Calcd for $C_{31}H_{28}N_2O_8Na$ $[M + Na]^+$ 579.1738; found 579.1728.

Fmoc-Glu(tBu)-ONHPI (2l)



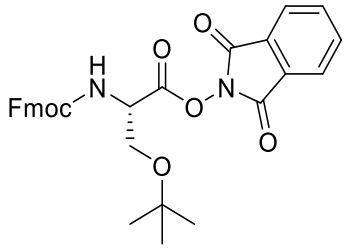
On 1.0 mmol scale, Fmoc-Glu(tBu)-ONHPI (**2l**) was obtained as a colorless oil (349.0 mg, 0.612 mmol, 61%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 – 7.79 (m, 2H), 7.78 – 7.68 (m, 4H), 7.65 – 7.55 (m, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.29 (t, *J* = 7.4 Hz, 2H), 5.92 (d, *J* = 8.3 Hz, 1H), 4.94 – 4.79 (m, 1H), 4.52 – 4.30 (m, 2H), 4.22 (t, *J* = 6.9 Hz, 1H), 2.60 – 2.46 (m, 2H), 2.46 – 2.32 (m, 1H), 2.31 – 2.16 (m, 1H), 1.48 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 172.0, 168.9, 161.4, 155.8, 143.8, 143.6, 141.2, 134.8, 128.7, 127.7, 127.1, 125.1, 124.0, 119.9, 81.2, 67.3, 52.1, 47.1, 31.2, 28.1, 27.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{32}H_{30}N_2O_8Na$ $[M + Na]^+$ 593.1894; found 593.1906.

Fmoc-Ser(tBu)-ONHPI (2m)



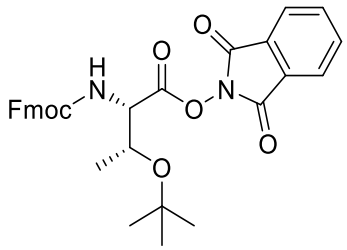
On 1.0 mmol scale, Fmoc-Ser(tBu)-ONHPI (**2m**) was obtained as a colorless oil (495.8 mg, 0.938 mmol, 94%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.92 – 7.83 (m, 2H), 7.83 – 7.73 (m, 4H), 7.62 (dd, *J* = 7.1, 3.3 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.4 Hz, 2H), 5.76 (d, *J* = 9.1 Hz, 1H), 4.98 (dt, *J* = 8.8, 2.5 Hz, 1H), 4.53 – 4.34 (m, 2H), 4.27 (t, *J* = 7.3 Hz, 1H), 4.05 (dd, *J* = 8.9, 2.7 Hz, 1H), 3.74 (dd, *J* = 9.0, 3.2 Hz, 1H), 1.28 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 167.6, 161.5, 155.9, 144.0, 143.8, 141.4, 134.9, 129.0, 127.8, 127.2, 125.3, 124.1, 120.1, 74.2, 67.6, 62.0, 53.6, 47.2, 27.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{30}H_{28}N_2O_7Na$ $[M + Na]^+$ 551.1789; found 551.1774.

Fmoc-Thr(tBu)-ONHPI (2n)



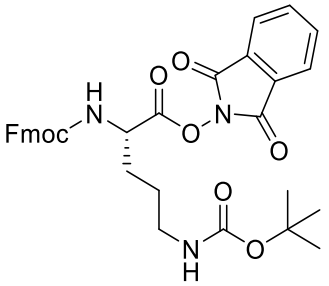
On 1.0 mmol scale, Fmoc-Thr(tBu)-ONHPI (**2n**) was obtained as a colorless foam (528.3 mg, 0.974 mmol, 97%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.82 – 7.71 (m, 4H), 7.70 – 7.57 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.3 Hz, 2H), 5.74 (d, *J* = 9.5 Hz, 1H), 4.75 – 4.68 (m, 1H), 4.53 – 4.37 (m, 3H), 4.29 (t, *J* = 7.1 Hz, 1H), 1.34 (d, *J* = 6.2 Hz, 3H), 1.28 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 167.9, 161.4, 156.4, 144.0, 143.8, 141.4, 134.8, 128.9, 127.8, 127.2, 125.3, 124.0, 120.0, 74.9, 67.5, 67.4, 58.8, 47.3, 28.7, 20.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{31}H_{30}N_2O_7Na$ [M + Na]$^+$ 565.1945; found 565.1943.

Fmoc-Orn(Boc)-ONHPI (2o)



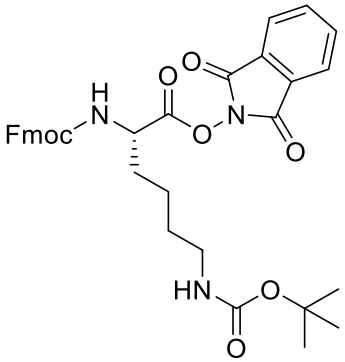
On 1.0 mmol scale, Fmoc-Orn(Boc)-ONHPI (**2o**) was obtained as a colorless foam (498.1 mg, 0.831 mmol, 83%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.93 – 7.85 (m, 2H), 7.84 – 7.73 (m, 4H), 7.62 (d, *J* = 7.6 Hz, 2H), 7.40 (t, *J* = 7.3 Hz, 2H), 7.32 (t, *J* = 7.1 Hz, 2H), 5.69 – 5.47 (m, 1H), 4.90 – 4.77 (m, 1H), 4.76 – 4.58 (m, 1H), 4.47 (d, *J* = 6.8 Hz, 2H), 4.25 (t, *J* = 5.6 Hz, 0H), 3.32 – 3.12 (m, 2H), 2.20 – 1.87 (m, 2H), 1.78 – 1.62 (m, 2H), 1.46 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.1, 161.5, 156.3, 155.8, 143.9, 143.7, 141.3, 134.9, 128.8, 127.8, 127.2, 125.2, 124.1, 120.0, 79.4, 67.3, 52.4, 47.2, 39.8, 29.7, 28.5, 25.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{33}H_{33}N_3O_8Na$ [M + Na]$^+$ 622.2160; found 622.2131.

Fmoc-Lys(Boc)-ONHPI (2p)



On 1.0 mmol scale, Fmoc-Lys(Boc)-ONHPI (**2p**) was obtained as a colorless solid (516.0 mg, 0.841 mmol, 84%).

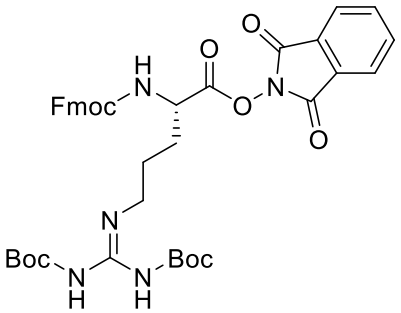
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.92 – 7.83 (m, 2H), 7.82 – 7.72 (m, 4H), 7.61 (d, *J* = 7.4 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.57 (d, *J* = 7.7 Hz, 1H), 4.87 – 4.67 (m,

2H), 4.53 – 4.31 (m, 2H), 4.24 (t, *J* = 7.0 Hz, 1H), 3.29 – 3.03 (m, 2H), 2.14 – 1.83 (m, 2H), 1.66 – 1.49 (m, 4H), 1.44 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.3, 161.6, 156.3, 155.8, 143.9, 143.7, 141.4, 135.0, 128.9, 127.8, 127.2, 125.2, 124.2, 120.1, 79.3, 67.4, 52.4, 47.2, 39.9, 32.1, 29.6, 28.6, 22.0 ppm.

HRMS (ESI, m/z): Calcd for $C_{34}H_{35}N_3O_8Na$ $[M + Na]^+$ 636.2316; found 636.2307.

Fmoc-Arg(Boc)$_2$-ONHPI (2q)



NOTE: Other arginine protecting groups (-Pbf, -Mtr, -Tos, -NO_2) have also been investigated. However, the corresponding NHPI esters could not be isolated due to the highly favored δ-lactam formation. This side reaction was likely suppressed in the present example by the steric hindrance of the dual Boc protection. However, it is expected that the described compound is not suitable for long-term storage.

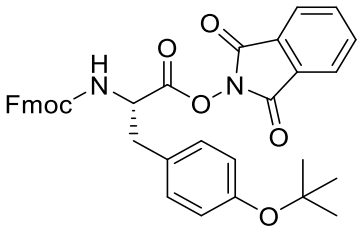
On 0.5 mmol scale, Fmoc-Arg(Boc)$_2$-ONHPI (**2q**) was obtained as a colorless foam (310.7 mg, 0.419 mmol, 84%).

^{1}H NMR (300 MHz $CDCl_3$) δ 11.51 (s, 1H), 8.42 (t, *J* = 4.9 Hz, 1H), 7.91 – 7.80 (m, 2H), 7.80 – 7.69 (m, 4H), 7.68 – 7.55 (m, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.33 – 7.26 (m, 2H), 6.26 (d, *J* = 8.5 Hz, 1H), 4.93 – 4.75 (m, 1H), 4.44 (d, *J* = 7.1 Hz, 2H), 4.23 (t, *J* = 6.7 Hz, 1H), 3.73 – 3.50 (m, 1H), 3.48 – 3.31 (m, 1H), 2.20 – 1.90 (m, 2H), 1.88 – 1.70 (m, 2H), 1.48 (s, 18H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 169.0, 163.4, 161.5, 156.5, 155.9, 153.3, 143.9, 143.7, 141.3, 134.9, 128.8, 127.7, 127.1, 125.3, 125.2, 124.0, 120.0, 83.2, 79.4, 67.2, 52.6, 47.2, 40.1, 29.0, 28.3, 28.1, 25.8 ppm.

HRMS (ESI, m/z): Calcd for $C_{39}H_{43}N_5O_{10}Na$ $[M + Na]^+$ 764.2902; found 764.2880.

Fmoc-Tyr(tBu)-ONHPI (2r)



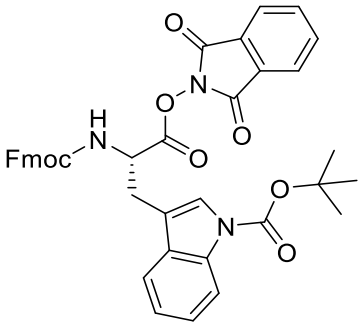
On 1.0 mmol scale, Fmoc-Tyr(tBu)-ONHPI (**2r**) was obtained as a pale yellow oil (491.8 mg, 0.813 mmol, 81%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.93 – 7.85 (m, 2H), 7.82 – 7.72 (m, 4H), 7.61 – 7.52 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 7.20 (d, *J* = 8.2 Hz, 2H), 6.96 (d, *J* = 8.4 Hz, 2H), 5.27 (d, *J* = 8.8 Hz, 1H), 5.17 – 5.05 (m, 1H), 4.51 – 4.28 (m, 2H), 4.21 (t, *J* = 6.9 Hz, 1H), 3.40 – 3.19 (m, 2H), 1.34 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.5, 161.5, 155.4, 155.0, 143.9, 143.7, 141.4, 135.0, 130.3, 129.2, 128.9, 127.8, 127.2, 125.2, 125.2, 124.4, 124.2, 120.1, 78.6, 67.3, 53.2, 47.2, 37.6, 29.0 ppm.

HRMS (ESI, m/z): Calcd for $C_{36}H_{32}N_2O_7Na$ $[M + Na]^+$ 627.2102; found 627.2100.

Fmoc-Trp(Boc)-ONHPI (2s)



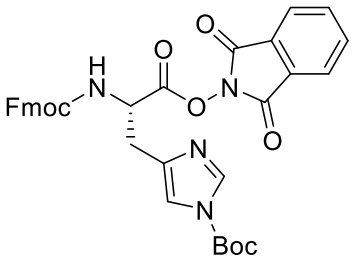
On 1.0 mmol scale, Fmoc-Trp(Boc)-ONHPI (**2s**) was obtained as a colorless foam (469.2 mg, 0.739 mmol, 74%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 8.23 (d, *J* = 7.9 Hz, 1H), 7.91 – 7.78 (m, 3H), 7.79 – 7.69 (m, 4H), 7.64 (d, *J* = 7.7 Hz, 1H), 7.58 – 7.46 (m, 2H), 7.44 – 7.34 (m, 3H), 7.33 – 7.22 (m, 3H), 5.64 (d, *J* = 8.6 Hz, 1H), 5.34 – 5.26 (m, 1H), 4.48 – 4.33 (m, 2H), 4.25 – 4.17 (m, 1H), 3.65 – 3.39 (m, 2H), 1.71 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.5, 161.3, 155.5, 149.5, 143.7, 143.5, 141.2, 135.5, 134.8, 130.5, 128.7, 127.7, 127.1, 125.1, 124.6, 123.9, 122.8, 119.9, 118.6, 115.4, 113.4, 83.6, 67.4, 52.9, 46.9, 28.1, 27.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{39}H_{33}N_3O_8Na$ $[M + Na]^+$ 694.2160; found 694.2147.

Fmoc-His(Boc)-ONHPI (2t)



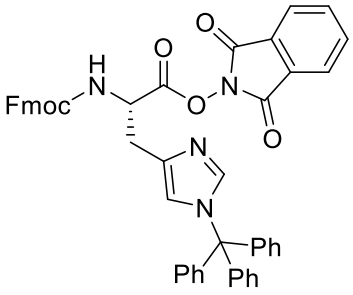
On 1.0 mmol scale, Fmoc-His(Boc)-ONHPI (**2t**) was obtained as a white foam (522.0 mg, 0.838 mmol, 84%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.88 – 7.79 (m, 2H), 7.79 – 7.70 (m, 4H), 7.66 – 7.57 (m, 2H), 7.49 (s, 1H), 7.37 (t, *J* = 7.3 Hz, 2H), 7.33 – 7.25 (m, 2H), 6.66 (d, *J* = 8.2 Hz, 1H), 5.20 – 5.06 (m, 1H), 4.45 – 4.31 (m, 2H), 4.25 (t, *J* = 7.3 Hz, 1H), 3.44 – 3.21 (m, 2H), 1.62 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 168.3, 161.4, 155.9, 146.8, 143.9, 143.8, 141.3, 137.1, 134.8, 134.0, 128.9, 127.7, 127.1, 125.4, 125.3, 124.0, 120.0, 116.1, 85.8, 67.6, 52.7, 47.1, 29.8, 27.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{34}H_{30}N_4O_8Na$ $[M + Na]^+$ 645.1956; found 645.1962.

Fmoc-His(Trt)-ONHPI (2u)



On 0.5 mmol scale, Fmoc-His(Trt)-ONHPI (**2u**) was obtained as a colorless solid (160.6 mg, 0.210 mmol, 42%).

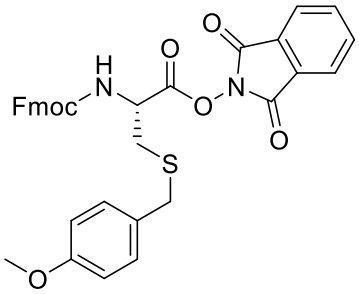
NOTE: Deactivated silica gel (100% SiO_2/35% H_2O) was used for chromatographic purification.

^{1}H NMR (300 MHz, CD_3CN) δ 7.86 – 7.70 (m, 6H), 7.58 (d, *J* = 7.2 Hz, 2H), 7.41 (s, 1H), 7.34 – 7.16 (m, 15H), 7.12 – 7.02 (m, 6H), 6.93 (s, 1H), 5.01 – 4.75 (m, 1H), 4.31 (d, *J* = 6.6 Hz, 2H), 4.15 (t, *J* = 6.5 Hz, 1H), 3.25 – 3.08 (m, 2H) ppm.

^{13}C NMR (75 MHz, CD_3CN) δ 169.8, 162.5, 156.7, 144.8, 143.2, 142.0, 136.1, 135.9, 135.0, 130.4, 129.4, 129.0, 128.9, 128.6, 128.0, 126.1, 124.8, 121.7, 120.9, 76.2, 67.6, 53.8, 47.8, 30.1 ppm.

HRMS (ESI, m/z): Calcd for $C_{48}H_{37}N_4O_6$ $[M + H]^+$ 765.2708; found 765.2702.

Fmoc-Cys(Mob)-ONHPI (2v)



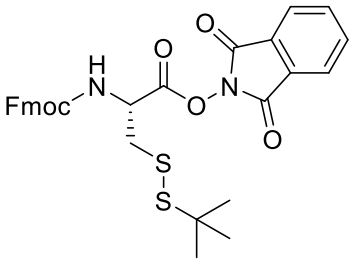
On 1.0 mmol scale, Fmoc-Cys(Mob)-ONHPI (**2v**) was obtained as a colorless solid (518.3 mg, 0.852 mmol, 85%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.93 – 7.82 (m, 2H), 7.82 – 7.71 (m, 4H), 7.61 (d, *J* = 7.3 Hz, 2H), 7.40 (t, *J* = 7.2 Hz, 2H), 7.35 – 7.23 (m, 4H), 6.89 – 6.81 (m, 2H), 5.66 (d, *J* = 8.5 Hz, 1H), 5.07 – 4.95 (m, 1H), 4.46 (d, *J* = 6.9 Hz, 2H), 4.26 (t, *J* = 6.9 Hz, 1H), 3.81 (s, 2H), 3.76 (s, 3H), 3.18 – 2.93 (m, 2H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 167.9, 161.4, 158.9, 155.6, 143.8, 143.7, 141.3, 135.0, 130.2, 129.3, 128.8, 127.8, 127.2, 125.2, 124.2, 120.1, 114.2, 67.6, 55.3, 52.1, 47.1, 36.2, 33.7 ppm.

HRMS (ESI, m/z): Calcd for $C_{34}H_{28}N_2O_7SNa$ $[M + Na]^+$ 631.1509; found 631.1504.

Fmoc-Cys(StBu)-ONHPI (2w)



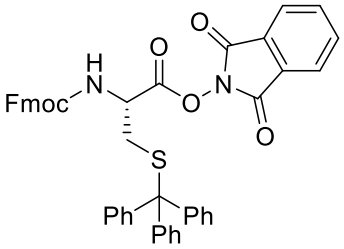
On 1.0 mmol scale, Fmoc-Cys(StBu)-ONHPI (**2w**) was obtained as a colorless solid (383.7 mg, 0.665 mmol, 67%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.91 – 7.83 (m, 2H), 7.80 – 7.72 (m, 4H), 7.63 (d, *J* = 7.1 Hz, 2H), 7.39 (t, *J* = 7.3 Hz, 2H), 7.31 (t, *J* = 7.2 Hz, 2H), 5.80 (d, *J* = 8.3 Hz, 1H), 5.23 – 5.10 (m, 1H), 4.52 – 4.36 (m, 2H), 4.27 (t, *J* = 7.0 Hz, 1H), 3.50 – 3.17 (m, 2H), 1.39 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 167.8, 161.4, 155.6, 143.8, 143.7, 141.3, 134.9, 128.8, 127.8, 127.2, 125.3, 124.1, 120.0, 67.7, 52.4, 48.6, 47.1, 42.1, 29.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{30}H_{28}N_2O_6S_2Na$ $[M + Na]^+$ 599.1281; found 599.1293.

Fmoc-Cys(Trt)-ONHPI (2x)



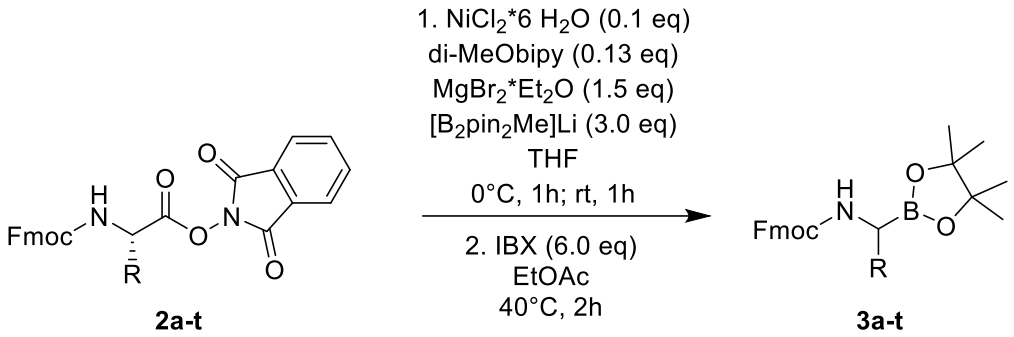
On 1.0 mmol scale, Fmoc-Cys(Trt)-ONHPI (**2x**) was obtained as a colorless foam (467.0 mg, 0.639 mmol, 64%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.91 – 7.83 (m, 2H), 7.82 – 7.72 (m, 4H), 7.60 (d, *J* = 7.2 Hz, 2H), 7.49 (d, *J* = 7.4 Hz, 6H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.36 – 7.18 (m, 11H), 5.14 (d, *J* = 8.2 Hz, 1H), 4.58 – 4.30 (m, 3H), 4.25 (t, *J* = 7.0 Hz, 1H), 2.97 – 2.77 (m, 2H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 167.6, 161.3, 155.4, 144.2, 143.9, 143.7, 141.4, 134.9, 129.7, 128.9, 128.3, 127.8, 127.2, 127.2, 125.3, 124.1, 120.1, 67.8, 67.4, 51.7, 47.2, 33.7 ppm.

HRMS (ESI, m/z): Calcd for $C_{45}H_{34}N_2O_6SNa$ $[M + Na]^+$ 753.2030; found 753.2034.

Synthesis of α-aminopinacolyl boronates



General procedure

Pinacolyl boronates were prepared by a modified, literature-known procedure.[4] Most tested α-amino pinacolyl boronates lacked stability even on deactivated silica or alumina columns. Thus, the workup was optimised, allowing to circumvent chromatography. It was found that stabilised 2-iodoxybenzoic acid (sIBX)[5] oxidatively destroys B_2pin_2 while leaving the C–B bond of α-amino pinacolyl boronates unharmed under the tested conditions.

A round-bottom flask was charged with the corresponding NHPI ester (1.0 eq) and $MgBr_2 \cdot OEt_2$ (1.5 eq). After evacuating and flushing the flask with nitrogen for three times, a suspension of $NiCl_2 \cdot 6\ H_2O$ (0.1 eq) and 4,4'-dimethoxy-2,2'-bipyridine (0.13 eq) in stabilised THF (4 mL/mmol), prepared 24 hours prior to use, was added. The suspension was stirred for 10 minutes at room temperature and then cooled to 0°C. Afterwards, a suspension of pre-complexed $[B_2pin_2Me]Li$ (3.0 eq) in stabilised THF (5 mL/mmol), prepared one hour prior to use, was added in one portion. The resulting mixture was stirred for one hour at 0°C and for one additional hour at ambient temperature. The suspension was diluted with ether (~50 mL/mmol) and quickly filtered through a short pad of celite and silica gel. After washing with additional ether (~100 mL/mmol), the filtrate was concentrated *in vacuo* to obtain the desired product containing B_2pin_2 and phthalimide as impurities.

Workup procedure (Route 1)

The crude product was dissolved in ethyl acetate (~50 mL/g of crude product). Stabilised 2-iodoxybenzoic acid[5] (sIBX, 6.0 eq) was added and the mixture was stirred for two hours at 40°C. The solvent was removed under reduced pressure, the residue was redissolved in methylene chloride and washed three times with aqueous K_2CO_3 solution (w = 10%) and once with saturated aqueous NaCl solution. The organic phase was dried over anhydrous $MgSO_4$ and dried *in vacuo* to obtain the corresponding pinacolyl boronate **3**.

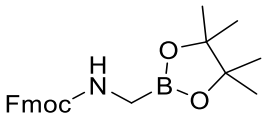
Workup procedure (Route 2)

The crude product was dissolved in methylene chloride and washed three times with aqueous K_2CO_3 solution (w = 10%) and once with saturated aqueous NaCl solution. The organic phase was dried over anhydrous $MgSO_4$ and dried *in vacuo* to obtain the corresponding pinacolyl boronate **3** as a crude containing B_2pin_2 contaminants.

NOTE: The organic phase should be washed thoroughly with K_2CO_3 solution to completely remove IBX stabilisers that are present in the material.

α-Aminopinacolyl boronates

Fmoc-Gly-Bpin (3a)



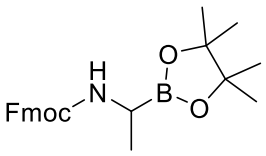
Route 1: On 0.681 mmol scale, Fmoc-Gly-Bpin (**3a**) was obtained as a pale yellow oil (117.5 mg, 0.310 mmol, 46%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.4 Hz, 2H), 7.62 (d, *J* = 7.3 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.31 (td, *J* = 7.4, 1.2 Hz, 2H), 4.99 – 4.88 (m, 1H), 4.39 (d, *J* = 7.0 Hz, 2H), 4.23 (t, *J* = 6.9 Hz, 1H), 2.90 (d, *J* = 4.4 Hz, 2H), 1.29 (s, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.5, 144.2, 141.3, 127.7, 127.1, 125.2, 120.0, 84.4, 66.9, 47.4, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{22}H_{26}BNO_4Na$ $[M + Na]^+$ 402.1851; found 402.1847.

Fmoc-Ala-Bpin ((±)-3b)



Route 1: On 0.656 mmol scale, Fmoc-Ala-Bpin ((±)-**3b**) was obtained as a colorless oil (150.6 mg, 0.383 mmol, 58%).

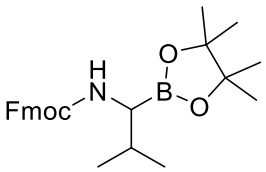
Route 2: On 0.486 mmol scale using compound **2b**, Fmoc-Ala-Bpin ((±)-**3b**) was obtained as a pale yellow crude material (254.5 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.5 Hz, 2H), 7.62 (d, *J* = 7.4 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (td, *J* = 7.4, 1.2 Hz, 2H), 5.02 (d, *J* = 5.8 Hz, 1H), 4.46 – 4.28 (m, 2H), 4.23 (t, *J* = 7.1 Hz, 1H), 3.29 – 3.15 (m, 1H), 1.27 – 1.23 (m, 15H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 156.9, 144.1, 144.0, 141.3, 127.6, 127.0, 125.2, 119.9, 84.1, 66.7, 47.3, 25.0, 16.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{23}H_{28}BNO_4Na$ $[M + Na]^+$ 416.2008; found 416.2005.

Fmoc-Val-Bpin ((±)-3c)



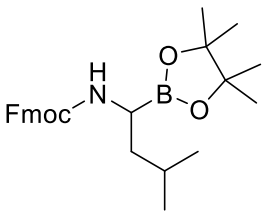
Route 1: On 0.887 mmol scale, Fmoc-Val-Bpin ((±)-**3c**) was obtained as a colorless oil (247.2 mg, 0.587 mmol, 66%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.5 Hz, 2H), 7.65 – 7.58 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.04 (d, *J* = 7.3 Hz, 1H), 4.46 – 4.29 (m, 2H), 4.25 (t, *J* = 7.2 Hz, 1H), 3.19 (dd, *J* = 7.3, 5.2 Hz, 1H), 2.08 – 1.90 (m, 1H), 1.29 – 1.23 (m, 13H), 1.02 – 0.80 (m, 6H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.1, 144.3, 144.2, 141.4, 127.7, 127.1, 125.3, 120.1, 84.2, 66.8, 47.5, 30.6, 25.1, 24.9, 20.0, 19.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{25}H_{32}BNO_4Na$ $[M + Na]^+$ 444.2321; found 444.2342.

Fmoc-Leu-Bpin ((±)-3d)



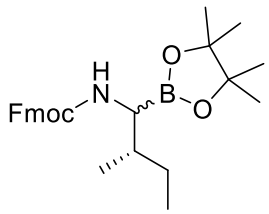
Route 1: On 0.772 mmol scale, Fmoc-Leu-Bpin ((±)-**3d**) was obtained as a pale yellow oil (234.6 mg, 0.539 mmol, 70%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.75 (d, *J* = 7.4 Hz, 2H), 7.66 – 7.56 (m, 2H), 7.38 (t, *J* = 7.4 Hz, 2H), 7.30 (t, *J* = 7.4 Hz, 2H), 4.97 (d, *J* = 6.5 Hz, 1H), 4.47 – 4.29 (m, 2H), 4.24 (t, *J* = 7.0 Hz, 1H), 3.26 (q, *J* = 7.1 Hz, 1H), 1.77 – 1.59 (m, 1H), 1.56 – 1.39 (m, 2H), 1.27 (s, 12H), 1.00 – 0.84 (m, 6H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 156.9, 144.2, 144.1, 141.3, 127.6, 127.0, 125.2, 119.9, 84.0, 66.7, 47.4, 40.4, 25.3, 24.9, 24.8, 23.2, 22.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{26}H_{34}BNO_4$ $[M + Na]^+$ 458.2478; found 458.2471.

Fmoc-Ile-Bpin (3e)



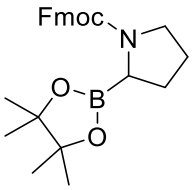
Route 1: On 0.712 mmol scale, Fmoc-Ile-Bpin (**3e**) was obtained as a pale yellow oil (160.9 mg, 0.370 mmol, 52%) as a mixture of diastereomers.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.5 Hz, 2H), 7.65 – 7.58 (m, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.3 Hz, 2H), 5.09 (d, *J* = 6.9 Hz, 0.5H, diastereomer), 5.04 (d, *J* = 8.2 Hz, 0.5H, diastereomer), 4.46 – 4.29 (m, 2H), 4.25 (t, *J* = 7.2 Hz, 1H), 3.36 (dd, *J* = 7.7, 4.2 Hz, 0.5H, diastereomer), 3.29 (dd, *J* = 7.3, 5.3 Hz, 0.5H, diastereomer), 1.84 – 1.65 (m, 1H), 1.62 – 1.39 (m, 2H), 1.26 (s, 12H), 1.17 – 1.03 (m, 1H), 0.98 – 0.83 (m, 6H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ (157.1 and 156.9, diastereomers), 144.3, 144.2, 141.4, 127.7, 127.1, 125.3, 120.0, 84.2, 66.7, 47.5, 37.4, 27.0, 25.1, 24.9, (16.8 and 16.7, diastereomers), (12.3 and 12.1, diastereomers) ppm.

HRMS (ESI, m/z): Calcd for $C_{26}H_{34}BNO_4Na$ $[M + Na]^+$ 458.2478; found 458.2467.

Fmoc-Pro-Bpin ((±)-3f)



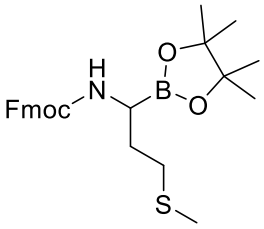
Route 1: On 0.908 mmol scale, Fmoc-Pro-Bpin ((±)-**3f**) was obtained as a colorless solid (231.3 mg, 0.552 mmol, 61%) as a mixture of rotamers.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.4 Hz, 2H), 7.71 – 7.59 (m, 2H), 7.45 – 7.35 (m, 2H), 7.35 – 7.27 (m, 2H), 4.69 – 4.00 (m, 3H), 3.63 – 3.42 (m, 2H), 3.42 – 3.32 (m, 0.5H, rotamer), 3.13 (dd, *J* = 9.7, 6.6 Hz, 0.5H, rotamer), 2.11 – 1.72 (m, 4H), 1.32 – 1.15 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 155.2, 144.9, 144.43, 144.41, 141.40, 141.36, 127.8, 127.7, 127.2, 127.1, 125.6, 125.5, 120.0, 83.9, 83.8, 67.4, 67.3, 47.7, 47.5, 47.3, 46.2, 29.1, 28.1, 27.2, 25.8, 25.01, 24.96, 24.7, 24.6 ppm.

HRMS (ESI, m/z): Calcd for $C_{25}H_{30}BNO_4Na$ $[M + Na]^+$ 442.2164; found 442.2155.

Fmoc-Met-Bpin ((±)-3g)



Route 2: On 0.784 mmol scale, Fmoc-Met-Bpin ((±)-**3g**) was obtained as a pale yellow crude material (350.7 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

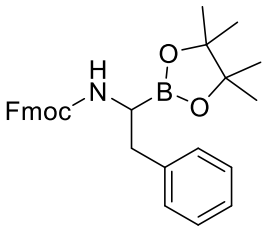
NOTE: For spectroscopic analysis, a small amount of Fmoc-Met-$B(OH)_2$ ((±)-**4g**) was esterified with pinacol (1.0 eq) in methylene chloride for one hour. After drying *in vacuo*, the title compound (±)-**3g** was obtained as a colorless solid.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.4 Hz, 2H), 7.64 – 7.57 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.10 (d, *J* = 6.5 Hz, 1H), 4.51 – 4.28 (m, 2H), 4.23 (t, *J* = 6.7 Hz, 1H), 3.36 – 3.25 (m, 1H), 2.61 – 2.43 (m, 2H), 2.08 (s, 3H), 2.06 – 1.96 (m, 1H), 1.94 – 1.79 (m, 1H), 1.27 (s, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.0, 144.3, 144.1, 141.5, 127.8, 127.2, 125.3, 120.1, 84.4, 66.8, 47.5, 31.5, 30.2, 25.0, 24.9, 15.5 ppm.

HRMS (ESI, m/z): Calcd for $C_{25}H_{32}BNO_4SNa$ $[M + Na]^+$ 476.2042; found 476.2048.

Fmoc-Phe-Bpin ((±)-3h)



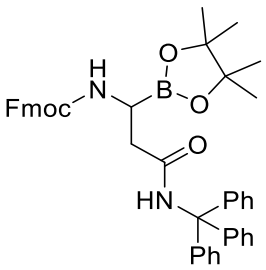
Route 1: On 0.783 mmol scale, Fmoc-Phe-Bpin ((±)-**3h**) was obtained as a colorless solid (168.6 mg, 0.359 mmol, 46%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.78 (d, *J* = 7.4 Hz, 2H), 7.62 (d, *J* = 7.4 Hz, 2H), 7.42 (t, *J* = 7.3 Hz, 2H), 7.37 – 7.15 (m, 7H), 4.98 (d, *J* = 6.2 Hz, 1H), 4.55 – 4.30 (m, 2H), 4.24 (t, *J* = 6.8 Hz, 1H), 3.46 (q, *J* = 6.3 Hz, 1H), 3.09 – 2.84 (m, 1H), 1.30 – 1.20 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.0, 144.1, 144.0, 141.4, 139.5, 129.5, 128.4, 127.7, 127.1, 126.4, 125.2, 120.0, 84.2, 66.8, 47.4, 36.8, 25.0, 24.8 ppm.

HRMS (ESI, m/z): Calcd for $C_{29}H_{32}BNO_4$ $[M + Na]^+$ 492.2322; found 492.2313.

Fmoc-Asn(Trt)-Bpin ((±)-3i)



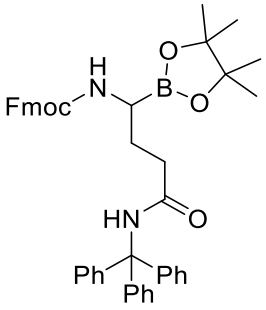
Route 1: On 0.800 mmol scale, Fmoc-Asn(Trt)-Bpin ((±)-**3i**) was obtained as a colorless solid (204.6 mg, 0.301 mmol, 38%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.81 – 7.70 (m, 2H), 7.66 – 7.54 (m, 2H), 7.46 – 7.35 (m, 2H), 7.34 – 7.13 (m, 17H, overlapping with the solvent signal), 6.63 (s, 1H), 5.53 (d, *J* = 7.7 Hz, 1H), 4.47 – 4.26 (m, 2H), 4.21 (t, *J* = 7.3 Hz, 1H), 3.39 – 3.26 (m, 1H), 2.87 – 2.66 (m, 2H), 1.27 (s, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.3, 144.5, 144.1, 144.0, 141.3, 128.7, 128.0, 127.6, 127.6, 127.1, 125.3, 119.9, 83.7, 71.0, 66.9, 47.3, 39.1, 24.8, 24.7 ppm.

HRMS (ESI, m/z): Calcd for $C_{43}H_{43}BN_2O_5Na$ $[M + Na]^+$ 701.3165; found 701.3152.

Fmoc-Gln(Trt)-Bpin ((±)-3j)



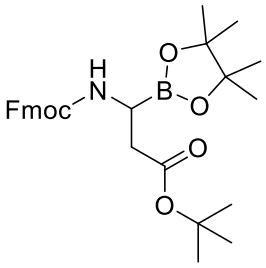
Route 1: On 0.780 mmol scale, Fmoc-Gln(Trt)-Bpin ((±)-**3j**) was obtained as a colorless solid (231.4 mg, 0.334 mmol, 43%).

^{1}H NMR (300 MHz, $CDCl_3$) δ δ 7.77 (d, *J* = 7.6 Hz, 2H), 7.64 (d, *J* = 7.4 Hz, 2H), 7.47 – 7.36 (m, 2H), 7.35 – 7.22 (m, 17H), 7.12 (s, 1H), 5.25 (d, *J* = 6.8 Hz, 1H), 4.50 – 4.34 (m, 2H), 4.26 (t, *J* = 6.9 Hz, 1H), 3.29 – 3.15 (m, 1H), 2.50 – 2.27 (m, 2H), 2.11 – 1.78 (m, 2H), 1.31 – 1.26 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 172.2, 157.6, 144.8, 144.1, 143.9, 141.3, 128.8, 127.9, 127.7, 127.1, 126.9, 125.2, 123.5, 120.0, 84.2, 70.6, 66.8, 47.4, 34.9, 27.9, 24.9, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{44}H_{45}BN_2O_5Na$ $[M + Na]^+$ 715.3321; found 715.3303.

Fmoc-Asp(tBu)-Bpin ((±)-3k)



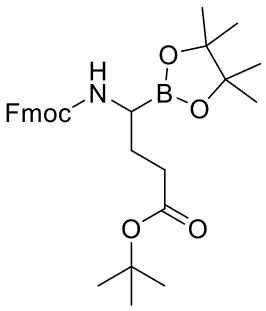
Route 1: On 0.897 mmol scale, Fmoc-Asp(tBu)-Bpin ((±)-**3k**) was obtained as a colorless oil (230.3 mg, 0.467 mmol, 52%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.74 (d, *J* = 7.5 Hz, 2H), 7.59 (t, *J* = 6.5 Hz, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.33 – 7.25 (m, 2H), 5.53 (d, *J* = 7.0 Hz, 1H), 4.41 – 4.26 (m, 2H), 4.21 (t, *J* = 7.2 Hz, 1H), 3.44 – 3.33 (m, 1H), 2.78 – 2.53 (m, 2H), 1.45 (s, 9H), 1.30 – 1.25 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 172.9, 156.9, 144.1, 143.9, 141.2, 127.6, 127.0, 125.2, 119.9, 84.3, 80.9, 66.9, 47.2, 37.4, 28.2, 24.9, 24.7 ppm.

HRMS (ESI, m/z): Calcd for $C_{28}H_{36}BNO_6Na$ $[M + Na]^+$ 516.2533; found 516.2529.

Fmoc-Glu(tBu)-Bpin ((±)-3l)



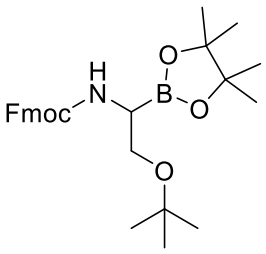
Route 1: On 0.587 mmol scale, Fmoc-Glu(tBu)-Bpin ((±)-**3l**) was obtained as a pale yellow oil (192.0 mg, 0.378 mmol, 64%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.75 (d, *J* = 7.4 Hz, 2H), 7.60 (dd, *J* = 7.2, 2.3 Hz, 2H), 7.38 (t, *J* = 7.3 Hz, 2H), 7.30 (t, *J* = 7.4 Hz, 2H), 5.18 (d, *J* = 6.4 Hz, 1H), 4.43 – 4.28 (m, 2H), 4.22 (t, *J* = 7.0 Hz, 1H), 3.18 (q, *J* = 6.3 Hz, 1H), 2.40 – 2.21 (m, 2H), 2.03 – 1.74 (m, 2H), 1.44 (s, 9H), 1.28 – 1.25 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 173.1, 157.1, 144.2, 144.0, 141.3, 127.7, 127.1, 125.2, 120.0, 84.2, 80.3, 66.9, 47.3, 33.1, 28.2, 26.8, 24.9, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{29}H_{38}BNO_6Na$ $[M + Na]^+$ 530.2690; found 530.2683.

Fmoc-Ser(tBu)-Bpin ((±)-3m)



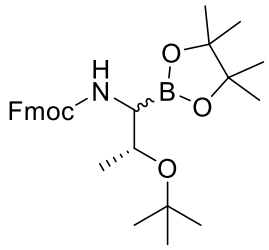
Route 1: On 0.727 mmol scale, Fmoc-Ser(tBu)-Bpin ((±)-**3m**) was obtained as a colorless oil (182.7 mg, 0.393 mmol, 54%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.4 Hz, 2H), 7.67 – 7.57 (m, 2H), 7.40 (t, *J* = 7.2 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.43 (d, *J* = 6.3 Hz, 1H), 4.45 – 4.29 (m, 2H), 4.25 (t, *J* = 7.1 Hz, 1H), 3.57 (d, *J* = 4.1 Hz, 2H), 3.40 – 3.30 (m, 1H), 1.29 (s, 12H), 1.17 (s, 9H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.3, 144.2, 144.1, 141.4, 127.7, 127.1, 125.3, 120.0, 84.1, 72.9, 67.0, 63.0, 47.4, 27.6, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{27}H_{36}BNO_5Na$ $[M + Na]^+$ 488.2584; found 488.2608.

Fmoc-Thr(tBu)-Bpin (3n)



Route 1: On 0.967 mmol scale, Fmoc-Thr(tBu)-Bpin (**3n**) was obtained as a pale yellow oil (295.2 mg, 0.616 mmol, 64%) as a mixture of diastereomers.

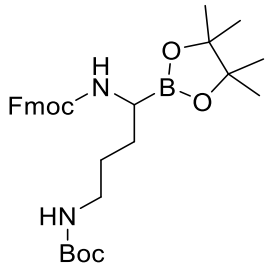
Route 2: On 0.471 mmol scale, Fmoc-Thr(tBu)-Bpin (**3n**) was obtained as a pale yellow crude material (316.7 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.5 Hz, 2H), 7.68 – 7.56 (m, 2H), 7.39 (t, *J* = 7.3 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.44 (d, *J* = 7.2 Hz, 0.5H, diastereomer), 5.37 (d, *J* = 4.4 Hz, 0.5H, diastereomer), 4.52 – 4.17 (m, 3H), 3.98 – 3.84 (m, 1H), 3.21 (dd, *J* = 7.0, 1.7 Hz, 0.5H, diastereomer), 2.88 (dd, *J* = 8.5, 4.6 Hz, 0.5H, diastereomer), 1.29 – 1.21 (m, 21H), 1.17 (d, *J* = 6.0 Hz, 3H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ (157.5 and 157.1, diastereomers), 144.1, 141.3, 127.7, 127.6, 127.1, 127.1, 125.3, 125.2, 120.1, 120.0, 84.1, 83.8, 73.9, 73.2, 70.3, 68.0, 67.3, 66.8, 47.4, 47.3, 28.9, 28.7, 25.1, 24.9, 24.8, 21.3, 20.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{28}H_{38}BNO_5Na$ $[M + Na]^+$ 502.2740; found 502.2760.

Fmoc-Orn(Boc)-Bpin ((±)-3o)



Route 1: On 0.747 mmol scale, Fmoc-Orn(Boc)-Bpin ((±)-**3o**) was obtained as a colorless solid (178.4 mg, 0.332 mmol, 45%).

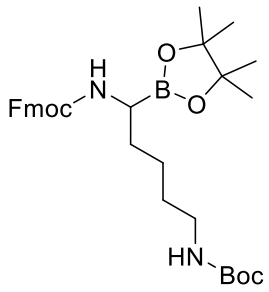
Route 2: On 0.830 mmol scale, Fmoc-Orn(Boc)-Bpin ((±)-**3o**) was obtained as a pale yellow crude material (475 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.5 Hz, 2H), 7.61 (d, *J* = 6.9 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 5.05 (d, *J* = 7.0 Hz, 1H), 4.70 – 4.57 (m, 1H), 4.48 – 4.28 (m, 2H), 4.22 (t, *J* = 6.9 Hz, 1H), 3.25 – 2.99 (m, 3H), 1.77 – 1.48 (m, 4H), 1.44 (s, 9H), 1.29 – 1.26 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.0, 156.1, 144.2, 144.0, 141.4, 127.7, 127.1, 125.2, 125.1, 120.0, 84.3, 79.1, 66.7, 47.4, 40.5, 28.7, 28.5, 27.3, 25.1, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{30}H_{41}BN_2O_6Na$ $[M + Na]^+$ 559.2955; found 559.2952.

Fmoc-Lys(Boc)-Bpin ((±)-**3p)**



Route 1: On 0.840 mmol scale, Fmoc-Lys(Boc)-Bpin ((±)-**3p**) was obtained as a pale yellow oil (143.2 mg, 0.428 mmol, 51%).

Route 2: On 0.845 mmol scale, Fmoc-Lys(Boc)-Bpin ((±)-**3p**) was obtained as a pale yellow crude material (466 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

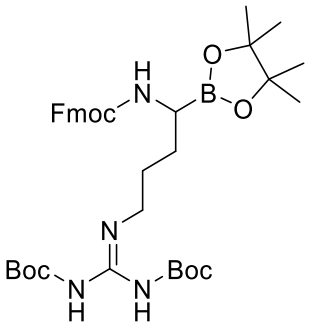
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.74 (d, *J* = 7.4 Hz, 2H), 7.62 – 7.55 (m, 2H), 7.37 (t, *J* = 7.4 Hz, 2H), 7.29 (t, *J* = 7.4 Hz, 2H), 5.10 (d, *J* = 5.7 Hz, 1H), 4.78 – 4.58 (m, 1H), 4.36 (t, *J* = 7.1

Hz, 2H), 4.21 (t, *J* = 7.0 Hz, 1H), 3.20 (q, *J* = 7.1, 6.6 Hz, 1H), 3.14 – 2.96 (m, 2H), 1.74 – 1.32 (m, 15H), 1.25 (s, 12H) ppm.

^{13}C NMR (75 MHz $CDCl_3$) δ 157.0, 156.1, 144.3, 144.2, 141.4, 127.7, 127.1, 125.3, 120.1, 84.3, 79.1, 66.8, 47.5, 40.6, 31.2, 29.9, 28.6, 25.0, 24.9, 24.0 ppm.

HRMS (ESI, m/z): Calcd for $C_{31}H_{43}BN_2O_6$ $[M + Na]^+$ 573.3112; found 573.3121.

Fmoc-Arg(Boc$_2$)-Bpin ((±)-3q)



Route 1: On 0.674 mmol scale, Fmoc-Arg(Boc$_2$)-Bpin ((±)-**3q**) was obtained as a colorless oil (213.6 mg, 0.315 mmol, 47%).

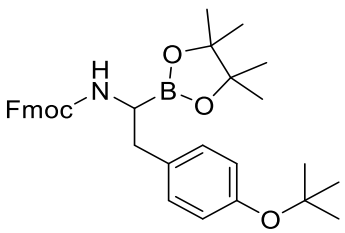
Route 2: On 0.419 mmol scale, Fmoc-Arg(Boc$_2$)-Bpin ((±)-**3q**) was obtained as a pale yellow crude material (243 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

^{1}H NMR (300 MHz, $CDCl_3$) δ 11.49 (s, 1H), 8.34 (t, *J* = 5.3 Hz, 1H), 7.76 (d, *J* = 7.5 Hz, 2H), 7.61 (d, *J* = 7.3 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.3 Hz, 2H), 5.12 (d, *J* = 6.5 Hz, 1H), 4.48 – 4.29 (m, 2H), 4.23 (t, *J* = 7.0 Hz, 1H), 3.40 (q, *J* = 6.8 Hz, 2H), 3.27 – 3.16 (m, 1H), 1.82 – 1.55 (m, 4H), 1.51 – 1.46 (m, 18H), 1.26 (s, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 163.7, 157.0, 156.3, 153.4, 144.3, 144.1, 141.4, 127.7, 127.1, 125.35, 125.29, 120.0, 84.3, 83.1, 79.3, 66.8, 47.5, 40.9, 28.7, 28.4, 28.2, 26.5, 25.0, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{36}H_{52}BN_4O_8$ $[M + H]^+$ 679.3879; found 679.3866.

Fmoc-Tyr(tBu)-Bpin ((±)-3r)



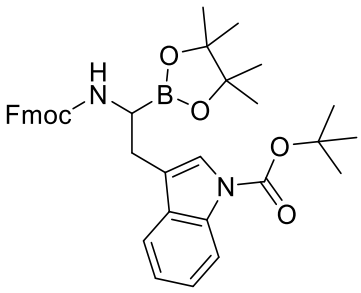
Route 1: On 0.482 mmol scale, Fmoc-Tyr(tBu)-Bpin ((±)-**3r**) was obtained as a yellow oil (147.2 mg, 0.272 mmol, 56%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.77 (d, *J* = 7.6 Hz, 2H), 7.61 (d, *J* = 7.4 Hz, 2H), 7.40 (t, *J* = 7.2 Hz, 2H), 7.31 (t, *J* = 7.5 Hz, 2H), 7.04 (d, *J* = 8.3 Hz, 2H), 6.88 (d, *J* = 8.3 Hz, 2H), 4.92 (d, *J* = 6.2 Hz, 1H), 4.54 – 4.30 (m, 2H), 4.23 (t, *J* = 6.6 Hz, 1H), 3.43 (q, *J* = 6.3 Hz, 1H), 3.03 – 2.64 (m, 2H), 1.32 (s, 9H), 1.25 – 1.16 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 156.9, 153.9, 144.3, 144.1, 141.5, 134.4, 130.0, 127.8, 127.2, 125.3, 125.2, 124.2, 120.1, 84.3, 78.4, 66.8, 47.5, 36.2, 29.0, 25.2, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{33}H_{40}BNO_5Na$ $[M + Na]^+$ 564.2898; found 564.2908.

Fmoc-Trp(Boc)-Bpin ((±)-3s)



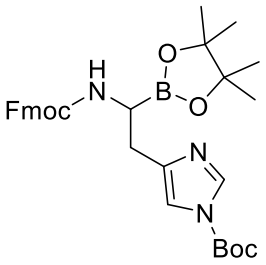
Route 1: On 0.710 mmol scale, Fmoc-Trp(Boc)-Bpin ((±)-**3s**) was obtained as a colorless oil (144.7 mg, 0.238 mmol, 34%).

^{1}H NMR (300 MHz, $CDCl_3$) δ 8.13 (d, *J* = 7.9 Hz, 1H), 7.76 (d, *J* = 7.5 Hz, 2H), 7.63 – 7.52 (m, 3H), 7.46 (s, 1H), 7.43 – 7.27 (m, 5H), 7.19 (t, *J* = 7.5 Hz, 1H), 5.07 (d, *J* = 5.9 Hz, 1H), 4.50 – 4.29 (m, 2H), 4.22 (t, *J* = 7.3 Hz, 1H), 3.61 – 3.49 (m, 1H), 3.23 – 2.94 (m, 2H), 1.65 (s, 9H), 1.26 – 1.19 (m, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.2, 149.8, 144.2, 144.1, 141.4, 135.6, 131.1, 127.8, 127.2, 125.4, 124.5, 123.7, 122.6, 120.0, 119.5, 118.5, 115.3, 84.4, 83.5, 67.2, 47.4, 28.4, 26.3, 25.0, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{36}H_{41}BN_2O_6Na$ $[M + Na]^+$ 631.2956; found 631.2962.

Fmoc-His(Boc)-Bpin ((±)-3t)



Route 1: On 0.819 mmol scale, Fmoc-His(Boc)-Bpin ((±)-**3t**) was obtained as a colorless oil (222.0 mg, 0.397 mmol, 48%).

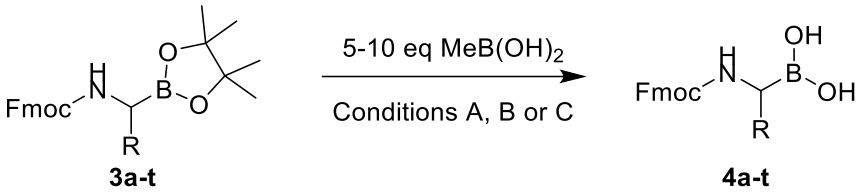
Route 2: On 0.434 mmol scale, Fmoc-His(Boc)-Bpin ((±)-**3t**) was obtained as a pale yellow crude material (196.5 mg, containing B_2pin_2 as impurity) that was directly used in the next step.

^{1}H NMR (300 MHz, $CDCl_3$) δ 8.02 (s, 1H), 7.75 (d, *J* = 7.5 Hz, 2H), 7.61 – 7.54 (m, 2H), 7.38 (t, *J* = 7.3 Hz, 2H), 7.32 – 7.27 (m, 2H), 7.12 (s, 1H), 5.48 (d, *J* = 5.9 Hz, 1H), 4.41 – 4.27 (m, 2H), 4.26 – 4.19 (m, 1H), 3.45 (q, *J* = 6.0, 5.4 Hz, 1H), 3.02 – 2.79 (m, 2H), 1.59 (s, 9H), 1.28 (s, 12H) ppm.

^{13}C NMR (75 MHz, $CDCl_3$) δ 157.2, 147.1, 144.2, 141.8, 141.4, 136.3, 127.7, 127.1, 125.4, 120.0, 113.9, 85.6, 83.9, 77.2, 67.0, 47.4, 29.2, 28.0, 25.0, 24.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{31}H_{38}BN_3O_6Na$ $[M + Na]^+$ 582.2751; found 582.2760.

Synthesis of α-aminoboronic acids



Fmoc-protected α-aminoboronic acids were obtained by modifying our recently published method.[6] The procedure was optimised for sensitive substrates.

Conditions A: MeCN/0.1 N HCl (1:1, v/v)

The respective Fmoc-protected pinacolyl boronate **3** (1.0 eq) was dissolved in acetonitrile (~10 mL/mmol). Methylboronic acid (5.0 eq) and dilute aqueous HCl (0.1 N, ~10 mL/mmol) were added and the resulting mixture was stirred at ambient temperature overnight. The solution was diluted with acetonitrile and deionised water, and volatiles were removed by freeze-drying to obtain the corresponding Fmoc-α-aminoboronic acid **4**.

Conditions B: MeCN/0.1 N HCl (9:1, v/v)

The respective Fmoc-protected pinacolyl boronate **3** (1.0 eq) was dissolved in acetonitrile (~10 mL/mmol). Methylboronic acid (10.0 eq) and dilute aqueous HCl (0.1 N, ~1 mL/mmol) were added and the resulting mixture was stirred at ambient temperature for two hours. The solution was diluted with acetonitrile and deionised water, and volatiles were removed by freeze-drying to obtain the corresponding Fmoc-α-aminoboronic acid **4**.

Conditions C: MeCN/phosphate buffer pH 7 (1:1, v/v)

The respective Fmoc-protected pinacolyl boronate **3** (1.0 eq) was dissolved in acetonitrile (~10 mL/mmol) and phosphate buffer pH 7.0 (~10 mL/mmol) After the addition of $MeB(OH)_2$ (10.0 eq), the resulting mixture was stirred at room temperature for two hours and concentrated *in vacuo*. The residue was redissolved in methylene chloride and deionised water, the aqueous phase was extracted twice with methylene chloride. The combined organic phases were washed with brine, dried over anhydrous $MgSO_4$ and concentrated *in vacuo* to obtain the corresponding Fmoc-α-aminoboronic acid **4**.

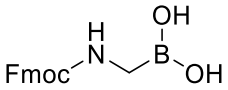
NOTE: Most Fmoc-protected α-aminoboronic acids could be stored at –20°C for several weeks without appreciable deterioration. However, it is expected that the compounds are prone to disproportionation and decomposition. Long-term storage should therefore be avoided.

Determination of loading efficiency onto 1-glycerol polystyrene resin

1-Glycerol polystyrene resin (100.0 mg, $B_{max.}$ = 0.60 mmol/g, 0.06 mmol) was weighed into a 5 mL polypropylene reaction vessel equipped with a polyethylene frit. The respective *N*-Fmoc-α-aminoboronic acid **4** (0.072 mmol, 1.2 eq) was dissolved in methylene chloride (1.5 mL) and added as a solution to the resin. The reaction vessel was shaken on an orbital shaker for two hours, before the resin was washed thoroughly with methylene chloride (9x) to remove unbound material. Cleavage was performed by treating the resin with a solution of DCM/MeOH/H_2O (5:4:1, v/v/v) for 3x30 min and collecting the cleavage fractions. The combined solutions were concentrated under reduced pressure to remove DCM and MeOH. The resulting suspension was diluted with acetonitrile and freeze-dried to constant weight. The loading efficiency is expressed by the molar fraction of freeze-dried compound and the theoretical scale of 0.06 mmol.

α-Aminoboronic acids

Fmoc-Gly-B(OH)$_2$ (4a)



On 0.148 mmol scale, conditions A were used to obtain Fmoc-Gly-B(OH)$_2$ (**4a**) as a colorless oil (41.3 mg, 0.139 mmol, 94%).

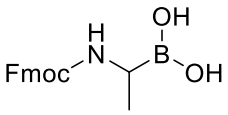
Loading efficiency: 66%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.82 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 7.5 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.36 – 7.30 (m, 2H), 4.30 (d, *J* = 7.0 Hz, 2H), 4.20 (t, *J* = 6.9 Hz, 1H), 2.61 (s, 2H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 158.6, 145.2, 142.1, 128.7, 128.2, 126.2, 121.0, 67.2, 48.1 ppm.

HRMS (ESI, m/z): Calcd for $C_{16}H_{16}BNO_4Na$ $[M + Na]^+$ 320.1067; found 320.1072.

Fmoc-Ala-B(OH)$_2$ ((±)-4b)



Route 1: Conditions A were used with Fmoc-Ala-Bpin ((±)-**3b**) on 0.252 mmol scale to obtain the title compound (±)-**4b** as a colorless solid (73.7 mg, 0.237 mmol, 94%).

Route 2: Crude (±)-**3b** (254.5 mg, 0.486 mmol based on **2b**) was transesterified using conditions A. After stirring at ambient temperature overnight, volatiles were removed *in vacuo*. The residue was redissolved in methanol and concentrated *in vacuo* twice, before it was dissolved in water/acetonitrile and lyophilised to obtain compound (±)-**4b** (80.1 mg, 0.257 mmol, 53%, 2 steps) as a colorless solid.

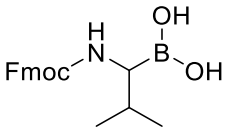
Loading efficiency: 81%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.6 Hz, 2H), 7.65 (d, *J* = 7.4 Hz, 2H), 7.40 (t, *J* = 7.5 Hz, 2H), 7.32 (t, *J* = 7.4 Hz, 2H), 4.33 – 4.24 (m, 2H), 4.20 (t, *J* = 6.8 Hz, 1H), 2.93 (q, *J* = 7.4 Hz, 1H), 1.11 (d, *J* = 7.5 Hz, 3H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 158.1, 145.21, 145.17, 142.1, 128.7, 128.1, 126.2, 121.0, 67.1, 48.1, 17.1 ppm.

HRMS (ESI, m/z): Calcd for $C_{17}H_{18}BNO_4Na$ $[M + Na]^+$ 334.1224; found 334.1234.

Fmoc-Val-B(OH)$_2$ ((±)-4c)



On 0.384 mmol scale, conditions A were used to obtain Fmoc-Val-B(OH)$_2$ ((±)-**4c**) as a colorless solid (125.1 mg, 0.369 mmol, 96%).

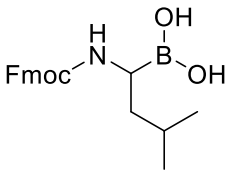
Loading efficiency: 46%

^{1}H NMR (300 MHz, CD_3CN/D_2O 9:1) δ 7.84 (d, *J* = 7.6 Hz, 2H), 7.69 (d, *J* = 7.4 Hz, 2H), 7.43 (t, *J* = 7.6 Hz, 2H), 7.35 (t, *J* = 7.4 Hz, 2H), 4.42 – 4.18 (m, 3H), 2.82 (d, *J* = 6.3 Hz, 1H), 1.94 – 1.81 (m, 1H), 0.89 (d, *J* = 6.8 Hz, 6H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 158.4, 145.3, 145.2, 142.1, 128.7, 128.1, 126.2, 121.0, 67.1, 48.2, 30.7, 20.7, 20.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{23}H_{30}BN_2O_4$ [DEA adduct + H]$^+$ 409.2297; found 409.2302.

Fmoc-Leu-B(OH)$_2$ ((±)-4d)



On 0.104 mmol scale, conditions A were used to obtain Fmoc-Leu-B(OH)$_2$ ((±)-**4d**) as a colorless solid (33.6 mg, 0.095 mmol, 91%).

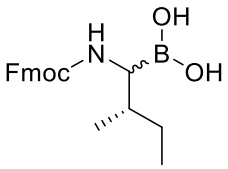
Loading efficiency: 60%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 7.5 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.4 Hz, 2H), 4.33 – 4.24 (m, 2H), 4.20 (t, *J* = 7.0 Hz, 1H), 2.95 (dd, *J* = 9.7, 5.2 Hz, 1H), 1.63 – 1.50 (m, 1H), 1.46 – 1.27 (m, 2H), 0.92 – 0.82 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 158.1, 145.3, 145.2, 142.1, 128.7, 128.1, 126.2, 121.0, 67.0, 48.2, 40.9, 26.0, 23.6, 22.2 ppm.

HRMS (ESI, m/z): Calcd for $C_{20}H_{24}BNO_4Na$ $[M + Na]^+$ 376.1694; found 376.1696.

Fmoc-Ile-B(OH)$_2$ (4e)



On 0.349 mmol scale, conditions A were used to obtain Fmoc-Ile-B(OH)$_2$ (**4e**) as a colorless solid (115.1 mg, 0.326 mmol, 93%) as a mixture of diastereomers.

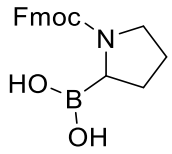
Loading efficiency: 64%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.82 (d, *J* = 7.5 Hz, 2H), 7.70 – 7.62 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.4 Hz, 2H), 4.35 – 4.24 (m, 2H), 4.21 (t, *J* = 6.8 Hz, 1H), 3.02 (d, *J* = 4.9 Hz, 0H), 1.68 – 1.56 (m, 1H), 1.48 – 1.31 (m, 1H), 1.15 – 1.03 (m, 1H), 0.91 – 0.79 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 158.3, 145.3, 145.2, 142.1, 128.7, 128.1, 126.2, 121.0, 67.1, 48.2, (37.6 and 37.5, diastereomers), (27.9 and 27.4, diastereomers), (17.3 and 17.1, diastereomers), (12.4 and 12.0, diastereomers) ppm.

HRMS (ESI, m/z): Calcd for $C_{20}H_{24}BNO_4Na$ $[M + Na]^+$ 376.1694; found 376.1697.

Fmoc-Pro-B(OH)$_2$ ((±)-4f)



On 0.284 mmol scale, conditions A were used to obtain Fmoc-Pro-B(OH)$_2$ ((±)-**4f**) as a colorless solid (93.2 mg, 0.276 mmol, 97%) as a mixture of rotamers.

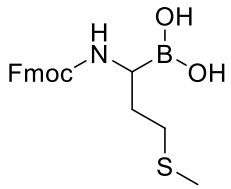
Loading efficiency: 60%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.84 – 7.78 (m, 2H), 7.72 – 7.63 (m, 2H), 7.43 – 7.36 (m, 2H), 7.36 – 7.29 (m, 2H), 4.38 – 4.18 (m, 3H), 3.46 – 3.33 (m, 1H), 3.34 – 3.23 (m, 1H), 3.15 – 3.10 (m, 0.5H, rotamer), 2.96 – 2.89 (m, 0.5H, rotamer), 2.13 – 1.96 (m, 1H), 1.92 – 1.84 (m, 1H), 1.82 – 1.63 (m, 2H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 156.4, 156.2, 145.5, 145.3, 145.2, 145.0, 142.1, 142.0, 128.7, 128.2, 126.5, 126.3, 126.2, 121.0, 118.7, 68.2, 67.8, 48.2, 48.1, 48.1, 47.3, 29.9, 28.9, 27.3, 26.5 ppm.

HRMS (ESI, m/z): Calcd for $C_{19}H_{20}BNO_4Na$ $[M + Na]^+$ 360.1381; found 360.1392.

Fmoc-Met-B(OH)$_2$ ((±)-4g)



Route 2: Crude (±)-**3g** (350.7 mg, 0.784 mmol based on **2g**) was transesterified using conditions A. After stirring at ambient temperature overnight, volatiles were removed *in vacuo*. The residue was redissolved in methanol and concentrated *in vacuo* twice, before it was dissolved in water/acetonitrile and lyophilised to obtain compound (±)-**4g** (107.8 mg, 0.290 mmol, 37%, 2 steps) as a colorless solid.

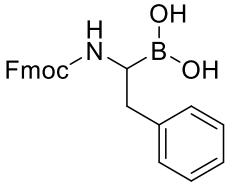
Loading efficiency: 43%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.83 (d, *J* = 7.6 Hz, 2H), 7.66 (d, *J* = 7.5 Hz, 2H), 7.41 (t, *J* = 7.3 Hz, 2H), 7.33 (td, *J* = 7.5, 1.1 Hz, 2H), 4.36 – 4.27 (m, 2H), 4.21 (t, *J* = 6.8 Hz, 1H), 3.04 – 2.96 (m, 1H), 2.53 – 2.39 (m, 2H), 2.03 (s, 3H), 1.88 – 1.69 (m, 2H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 145.3, 145.2, 142.1, 128.7, 128.1, 126.2, 121.0, 67.0, 48.2, 32.2, 31.4, 15.3 ppm. (carbamate not observed)

HRMS (ESI, m/z): Calcd for $C_{19}H_{22}BNO_4SNa$ $[M + Na]^+$ 394.1258; found 394.1260.

Fmoc-Phe-B(OH)$_2$ ((±)-4h)



On 0.133 mmol scale, conditions A were used to obtain Fmoc-Phe-B(OH)$_2$ ((±)-**4h**) as a colorless solid (46.9 mg, 0.121 mmol, 91%).

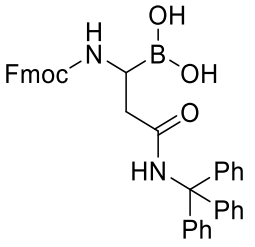
Loading efficiency: 46%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.60 (d, *J* = 7.5 Hz, 2H), 7.40 (t, *J* = 7.5 Hz, 2H), 7.35 – 7.29 (m, 2H), 7.22 (t, *J* = 7.3 Hz, 2H), 7.19 – 7.09 (m, 3H), 4.33 – 4.23 (m, 2H), 4.16 (t, *J* = 6.8 Hz, 1H), 3.16 (dd, *J* = 8.6, 5.4 Hz, 1H), 2.93 – 2.83 (m, 1H), 2.78 – 2.69 (m, 1H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 158.0, 145.1, 142.1, 141.1, 130.1, 129.2, 128.7, 128.1, 127.0, 126.2, 121.0, 67.0, 48.1, 37.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{23}H_{22}BNO_4Na$ $[M + Na]^+$ 410.1538; found 410.1551.

Fmoc-Asn(Trt)-B(OH)$_2$ ((±)-4i)



On 0.309 mmol scale, conditions A were used to obtain Fmoc-Asn(Trt)-B(OH)$_2$ ((±)-**4i**) as a colorless solid (155.1 mg, 0.260 mmol, 84%).

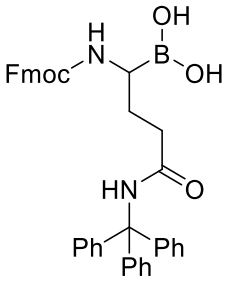
Loading efficiency: 44%

^{1}H NMR (300 MHz, CD_3CN/D_2O 9:1) δ 7.84 – 7.75 (m, 2H), 7.64 (d, *J* = 7.5 Hz, 2H), 7.38 (t, *J* = 7.7 Hz, 2H), 7.31 – 7.14 (m, 17H), 4.36 – 4.28 (m, 2H), 4.20 (t, *J* = 6.9 Hz, 1H), 3.18 – 3.10 (m, 1H), 2.71 – 2.51 (m, 2H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 173.6, 158.1, 145.6, 145.2, 145.1, 142.1, 129.6, 128.7, 128.7, 128.2, 127.8, 126.2, 121.0, 71.1, 67.2, 48.1, 39.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{37}H_{33}BN_2O_5Na$ $[M + Na]^+$ 410.1538; found 410.1532.

Fmoc-Gln(Trt)-B(OH)$_2$ ((±)-4j)



On 0.330 mmol scale, conditions A were used to obtain Fmoc-Gln(Trt)-B(OH)$_2$ ((±)-**4j**) as a colorless solid (190.8 mg, 0.313 mmol, 95%).

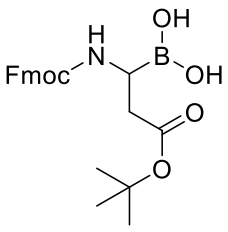
Loading efficiency: 62%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 7.5 Hz, 2H), 7.39 (t, *J* = 7.5 Hz, 2H), 7.31 (t, *J* = 7.3 Hz, 2H), 7.29 – 7.16 (m, 16H), 4.37 – 4.25 (m, 2H), 4.21 (t, *J* = 6.9 Hz, 1H), 2.89 (dd, *J* = 8.9, 5.3 Hz, 1H), 2.39 – 2.19 (m, 2H), 1.85 – 1.72 (m, 1H), 1.72 – 1.59 (m, 1H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 174.3, 158.3, 145.7, 145.2, 142.1, 129.6, 128.7, 128.7, 128.2, 127.7, 126.2, 121.0, 70.8, 67.1, 48.2, 35.1, 28.2 ppm.

HRMS (ESI, m/z): Calcd for $C_{38}H_{35}BN_2O_5Na$ $[M + Na]^+$ 633.2538; found 633.2543.

Fmoc-Asp(tBu)-B(OH)$_2$ ((±)-4k)



On 0.197 mmol scale, conditions B were used to obtain Fmoc-Asp(tBu)-$B(OH)_2$ ((±)-**4k**) as a colorless solid (77.0 mg, 0.187 mmol, 95%).

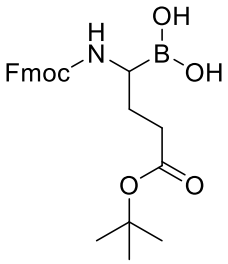
Loading efficiency: 71%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.62 (d, *J* = 7.5 Hz, 2H), 7.40 (t, *J* = 7.2 Hz, 2H), 7.35 – 7.28 (m, 2H), 4.34 – 4.24 (m, 2H), 4.20 (t, *J* = 6.8 Hz, 1H), 3.06 (dd, *J* = 6.8, 2.5 Hz, 0H), 2.65 – 2.43 (m, 2H), 1.39 (s, 9H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 173.6, 157.9, 145.2, 145.1, 142.1, 128.7, 128.1, 126.2, 121.0, 81.8, 67.2, 48.1, 38.3, 28.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{22}H_{26}BNO_6Na$ $[M + Na]^+$ 434.1749; found 434.1751.

Fmoc-Glu(tBu)-$B(OH)_2$ ((±)-4l)



On 0.381 mmol scale, conditions B were used to obtain Fmoc-Glu(tBu)-$B(OH)_2$ ((±)-**4l**) as a colorless solid (147.6 mg, 0.347 mmol, 91%).

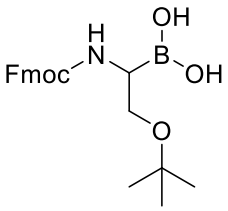
Loading efficiency: 84%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 7.1 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.5 Hz, 2H), 4.34 – 4.25 (m, 2H), 4.20 (t, *J* = 7.0 Hz, 1H), 2.91 (dd, *J* = 8.3, 5.2 Hz, 1H), 2.22 – 2.16 (m, 2H), 1.87 – 1.76 (m, 1H), 1.73 – 1.62 (m, 1H), 1.40 (s, 9H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 174.4, 158.2, 145.2, 145.2, 142.1, 128.7, 128.1, 126.2, 121.0, 81.1, 67.1, 48.2, 33.8, 28.3, 27.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{23}H_{28}BNO_6Na$ $[M + Na]^+$ 448.1906; found 448.1914.

Fmoc-Ser(tBu)-B(OH)$_2$ ((±)-4m)



On 0.399 mmol scale, conditions B were used to obtain Fmoc-Ser(tBu)-B(OH)$_2$ ((±)-**4m**) as a colorless solid (145.8 mg, 0.380 mmol, 95%).

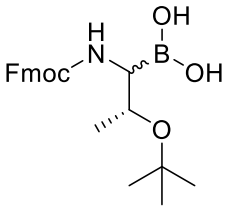
Loading efficiency: 67%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 7.4 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.9 Hz, 2H), 4.34 – 4.26 (m, 2H), 4.20 (t, *J* = 6.9 Hz, 1H), 3.52 – 3.42 (m, 2H), 3.05 – 3.00 (m, 1H), 1.12 (s, 9H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 158.2, 145.2, 145.1, 142.1, 128.7, 128.1, 126.2, 121.0, 118.7, 74.0, 67.2, 63.2, 48.1, 27.7 ppm.

HRMS (ESI, m/z): Calcd for $C_{21}H_{26}BNO_5Na$ $[M + Na]^+$ 406.1800; found 406.1792.

Fmoc-Thr(tBu)-B(OH)$_2$ (4n)



On 0.617 mmol scale, conditions C were used to obtain Fmoc-Thr(tBu)-B(OH)$_2$ (**4n**) as a colorless solid (180.4 mg, 0.454 mmol, 74%) as a mixture of diastereomers.

Route 2: Crude **3n** (316.7 mg, 0.471 mmol based on **2n**) was transesterified using conditions C. After stirring at ambient temperature for two hours, volatiles were removed *in vacuo*. The residue was redissolved in methylene chloride and water and the aqueous phase was extracted twice with methylene chloride. The combined organic phases were washed with brine, dried over anhydrous $MgSO_4$ and concentrated *in vacuo.* The residue was dissolved in water/acetonitrile and lyophilised to obtain compound **4n** (103.5 mg, 0.261 mmol, 55%, 2 steps) as a colorless solid.

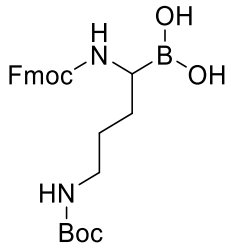
Loading efficiency: 66%

^{1}H NMR (300 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 7.4 Hz, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.4 Hz, 2H), 4.43 – 4.25 (m, 2H), 4.20 (t, *J* = 6.6 Hz, 1H), 3.99 – 3.87 (m, 1H), 3.10 (d, *J* = 5.8 Hz, 1H), 1.18 (s, 9H), 1.02 (d, *J* = 6.2 Hz, 3H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 158.1, 145.3, 145.0, 142.1, 128.7, 128.1, 126.2, 126.2, 121.0, 75.6, 68.4, 67.1, 48.2, 28.5, 20.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{22}H_{28}BNO_5Na$ $[M + Na]^+$ 420.1957; found 420.1970.

Fmoc-Orn(Boc)-B(OH)$_2$ ((±)-4o)



Route 1: On 0.559 mmol scale, conditions B were used to obtain Fmoc-Orn(Boc)-B(OH)$_2$ ((±)-**4o**) as a colorless solid (235.0 mg, 0.517 mmol, 93%).

Route 2: Crude compound **(±)-3o** (475 mg, 0.830 mmol based on **2o**) was transesterified using conditions B. After stirring at ambient temperature for two hours, volatiles were removed *in vacuo*. The residue was redissolved in methanol and concentrated *in vacuo* twice, before it was dissolved in water/acetonitrile and lyophilised to obtain compound **(±)-4o** (146.8 mg, 0.323 mmol, 39%, 2 steps) as a colorless solid.

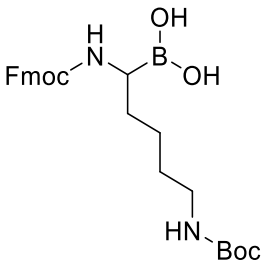
Loading efficiency: 84%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.6 Hz, 2H), 7.68 – 7.62 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.35 – 7.29 (m, 2H), 4.34 – 4.23 (m, 2H), 4.23 – 4.17 (m, 1H), 3.02 – 2.87 (m, 3H), 1.68 – 1.26 (m, 13H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 158.2, 157.5, 145.2, 145.1, 142.1, 128.7, 128.1, 126.2, 121.0, 79.5, 67.1, 48.1, 40.8, 29.1, 28.7, 28.2 ppm.

HRMS (ESI, m/z): Calcd for $C_{24}H_{31}BN_2O_6Na$ $[M + Na]^+$ 477.2172; found 477.2177.

Fmoc-Lys(Boc)-B(OH)$_2$ ((±)-4p)



Route 1: On 0.252 mmol scale, conditions B were used to obtain Fmoc-Lys(Boc)-B(OH)$_2$ ((±)-**4p**) as a colorless solid (111.9 mg, 0.239 mmol, 95%).

Route 2: Crude (±)-**3p** (466 mg, 0.845 mmol based on **2p**) was transesterified using conditions B. After stirring at ambient temperature for two hours, volatiles were removed *in vacuo*. The residue was redissolved in methanol and concentrated *in vacuo* twice, before it was dissolved in water/acetonitrile and lyophilised to obtain compound (±)-**4p** (141.1 mg, 0.301 mmol, 36%, 2 steps) as a colorless solid.

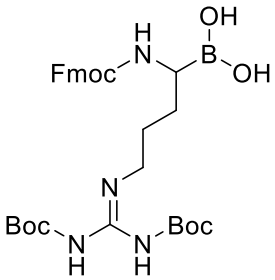
Loading efficiency: 66%

^{1}H NMR (500 MHz, CD$_3$CN/D$_2$O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.67 – 7.62 (m, 2H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.32 (t, *J* = 7.9 Hz, 2H), 4.34 – 4.24 (m, 2H), 4.20 (t, *J* = 6.9 Hz, 1H), 3.00 – 2.82 (m, 3H), 1.68 – 1.39 (m, 4H), 1.36 (s, 9H), 1.30 – 1.19 (m, 2H) ppm.

^{13}C NMR (75 MHz, CD$_3$CN/D$_2$O 9:1) δ 158.2, 157.5, 145.2, 145.1, 142.1, 128.7, 128.2, 126.2, 121.0, 79.4, 67.1, 48.1, 40.8, 31.5, 30.5, 28.7, 24.8 ppm.

HRMS (ESI, m/z): Calcd for $C_{25}H_{33}BN_2O_6Na$ $[M + Na]^+$ 491.2328; found 491.2339.

Fmoc-Arg(Boc)$_2$-B(OH)$_2$ ((±)-4q)



Route 1: Conditions C were used with Fmoc-Arg(Boc)$_2$-Bpin ((±)-**3q**) on 0.250 mmol scale to obtain the title compound (±)-**4q** (84.7 mg, 0.142 mmol, 57%) as a colorless oil.

Route 2: Crude (±)-**3q** (243 mg, 0.419 mmol based on **2q**) was transesterified using conditions C. After stirring at ambient temperature for two hours, volatiles were removed *in vacuo*. The residue was redissolved in methylene chloride and water, the aqueous phase was extracted twice with methylene chloride. The combined organic phases were washed with brine, dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The residue was dissolved in water/acetonitrile and lyophilised to obtain compound (±)-**4q** (56.3 mg, 0.094 mmol, 23%, 2 steps) as a colorless solid.

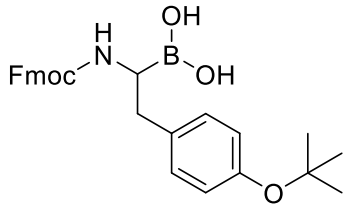
Loading efficiency: 54%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 6.7 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.4 Hz, 2H), 4.35 – 4.25 (m, 2H), 4.20 (t, *J* = 6.9 Hz, 1H), 3.32 – 3.23 (m, 2H), 2.95 – 2.91 (m, 1H), 1.59 – 1.46 (m, 4H), 1.45 (s, 9H), 1.40 (s, 9H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 164.4, 158.2, 156.9, 153.8, 145.2, 145.1, 142.1, 128.7, 128.1, 126.2, 121.0, 84.2, 79.8, 67.1, 48.2, 41.2, 28.9, 28.5, 28.2, 27.4 ppm.

HRMS (ESI, m/z): Calcd for $C_{30}H_{42}BN_4O_8$ $[M + H]^+$ 597.3096; found 597.3100.

Fmoc-Tyr(tBu)-B(OH)$_2$ ((±)-4r)



On 0.255 mmol scale, conditions B were used to obtain Fmoc-Tyr(tBu)-B(OH)$_2$ ((±)-**4r**) as a pale yellow solid (115.8 mg, 0.252 mmol, 99%).

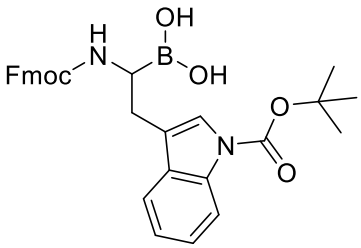
Loading efficiency: 26%

^{1}H NMR (300 MHz, CD_3CN/D_2O 9:1) δ 7.81 (d, *J* = 7.4 Hz, 2H), 7.61 (d, *J* = 7.2 Hz, 2H), 7.40 (t, *J* = 7.6 Hz, 2H), 7.32 (t, *J* = 7.4 Hz, 2H), 7.01 (d, *J* = 8.3 Hz, 2H), 6.81 (d, *J* = 8.3 Hz, 2H), 4.34 – 4.19 (m, 2H), 4.14 (t, *J* = 6.6 Hz, 1H), 3.13 (dd, *J* = 9.0, 5.5 Hz, 1H), 2.91 – 2.62 (m, 2H), 1.22 (s, 9H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 154.4, 149.3, 145.2, 142.1, 136.1, 130.6, 128.7, 128.1, 126.2, 124.8, 121.0, 79.0, 67.0, 48.1, 36.8, 29.0 ppm.

HRMS (ESI, m/z): Calcd for $C_{27}H_{30}BNO_5Na$ $[M + Na]^+$ 482.2114; found 482.2107.

Fmoc-Trp(Boc)-B(OH)$_2$ ((±)-4s)



On 0.238 mmol scale, conditions B were used to obtain Fmoc-Trp(Boc)-B(OH)$_2$ ((±)-**4s**) as a pale yellow solid (114.5 mg, 0.218 mmol, 91%).

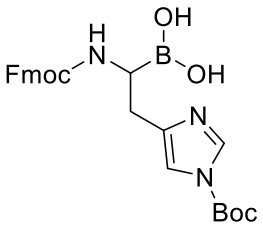
Loading efficiency: 49%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 8.04 (d, *J* = 8.2 Hz, 1H), 7.78 (d, *J* = 7.6 Hz, 2H), 7.59 (d, *J* = 7.8 Hz, 1H), 7.53 (t, *J* = 7.8 Hz, 2H), 7.45 (s, 1H), 7.36 (t, *J* = 7.5 Hz, 2H), 7.31 – 7.16 (m, 4H), 4.26 – 4.18 (m, 2H), 4.13 (t, *J* = 7.1 Hz, 1H), 3.29 (dd, *J* = 8.8, 5.3 Hz, 1H), 3.05 – 2.86 (m, 2H), 1.53 (s, 9H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 158.1, 150.8, 145.1, 142.0, 136.3, 131.9, 128.7, 128.1, 126.2, 126.2, 125.2, 124.5, 123.4, 120.9, 120.3, 119.8, 115.9, 84.6, 67.2, 48.1, 28.3, 26.8 ppm.

HRMS (ESI, m/z): Calcd for $C_{30}H_{31}BN_2O_6Na$ $[M + Na]^+$ 549.2173; found 549.2175.

Fmoc-His(Boc)-B(OH)$_2$ ((±)-4t)



Route 1: On 0.351 mmol scale, conditions C were used to obtain Fmoc-His(Boc)-B(OH)$_2$ ((±)-**4t**) as a colorless solid (81.2 mg, 0.170 mmol, 48%).

Route 2: Crude (±)-**3t** (196.5 mg, 0.434 mmol based on **2t**) was transesterified using conditions C. After stirring at ambient temperature for two hours, volatiles were removed *in vacuo*. The residue was redissolved in methylene chloride and water, the aqueous phase was extracted twice with methylene chloride. The combined organic phases were washed with brine, dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The residue was dissolved in water/acetonitrile

and lyophilised to obtain compound (±)-**4t** (62.3 mg, 0.131 mmol, 30%, 2 steps) as a colorless solid.

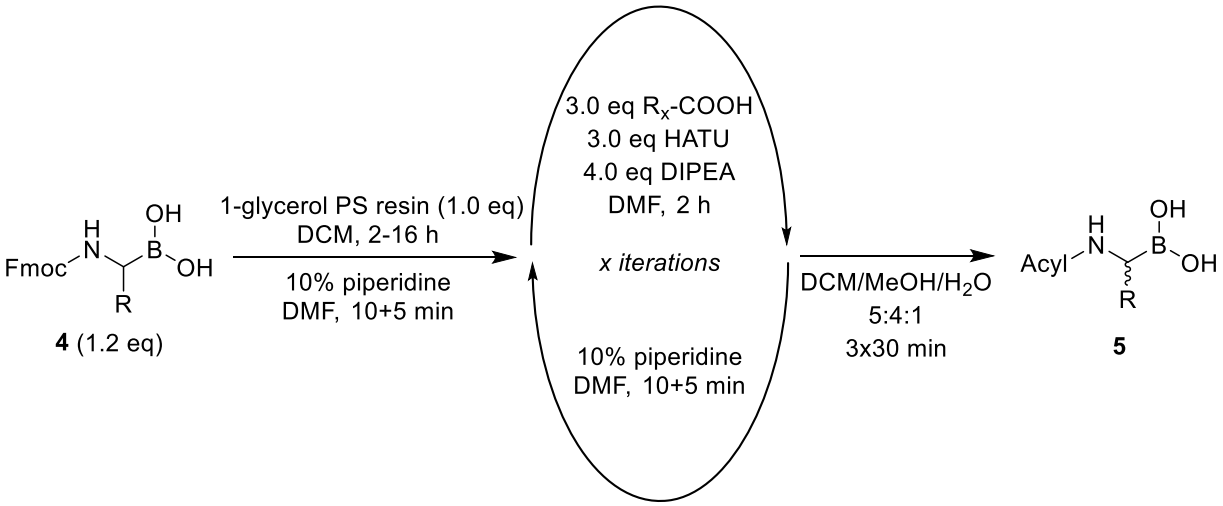
Loading efficiency: 70%

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 8.05 (s, 1H), 7.79 (d, *J* = 7.1 Hz, 2H), 7.61 – 7.53 (m, 2H), 7.38 (t, *J* = 7.1 Hz, 2H), 7.33 – 7.25 (m, 2H), 7.19 (s, 1H), 4.28 – 4.17 (m, 2H), 4.16 – 4.10 (m, 1H), 3.20 – 3.16 (m, 1H), 2.85 – 2.66 (m, 2H), 1.47 (s, 9H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 158.1, 148.0, 145.1, 142.0, 141.8, 137.9, 128.7, 128.1, 126.2, 126.2, 120.9, 115.3, 86.7, 67.2, 48.0, 30.0, 27.9 ppm.

HRMS (ESI, m/z): Calcd for $C_{25}H_{28}BN_3O_6Na$ $[M + Na]^+$ 500.1968; found 500.1959.

Solid-phase synthesis of peptide-boronic acids



General procedure

The standard protocol was elaborated adopting a literature-known method with slight modifications.[7] The use of THF was generally avoided in this work, because oxidised byproducts, namely *N*-acyl hemiaminals, were observed in some attempts. DMF was stored over molecular sieves (4Å) to avoid premature cleavage from the resin.

A 5 mL PP reaction vessel equipped with a PE frit was charged with 1-glycerol polystyrene resin (1.0 eq, max. loading: B = 0.6 mmol/g). The respective Fmoc-protected α-aminoboronic acid **4** (1.2 eq) was dissolved in DCM (~ 1 mL/50 µmol) and added to the resin. The suspension was continuously shaken at ambient temperature for two hours and the resin was washed (6× DCM, 6× DMF). Subsequently, the desired sequence was assembled by alternating Fmoc deprotection and amide coupling steps.

Fmoc deprotection was achieved by treating the resin with 10% piperidine solution in DMF for 10 min + 5 min. Afterwards, the resin was washed thoroughly (6× DMF, 3× DCM, 3× DMF). For amide coupling, the corresponding carboxylic acid (3.0 eq), HATU (3.0 eq) and DIPEA (4.0 eq) were dissolved in DMF (1 mL) and added to the reaction vessel. After shaking for two hours, the resin was washed (3× DMF, 3× DCM, 3× DMF).

NOTE: When residues were coupled that are prone to racemisation, e. g. phenylglycine derivatives, COMU and TMP were used as coupling reagents instead of HATU and DIPEA to avoid epimer formation, as it was described recently.[8]

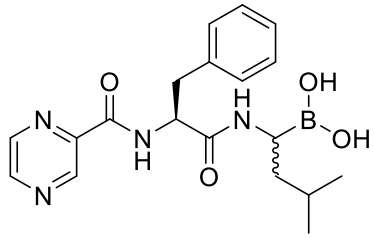
After the final coupling step, the resin was washed (6× DMF, 9× DCM). Cleavage from solid support was achieved under complete conservation of side-chain protecting groups using

DCM/MeOH/H_2O (5:4:1, v/v) for 3×30 min. The combined cleavage solutions were collected, DCM and MeOH were removed under reduced pressure. The resulting suspension was diluted with MeCN and lyophilised. Final compounds were obtained as diastereomers if more than one stereocentre was present.

NOTE: The loading step could also be performed overnight. The synthesis of longer sequences could be paused overnight. In that case, the resin was washed (3× DMF, 6× DCM) after amide coupling and dried in a desiccator overnight. The resin was swollen in DCM for 30 min, washed (3× DMF) and the synthesis was continued with Fmoc deprotection.

Peptide-boronic acids

Bortezomib (5a)



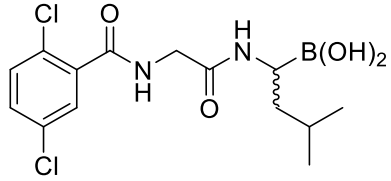
On 0.12 mmol scale, bortezomib (**5a**) was obtained as a colorless solid after HPLC purification (16.1 mg, 0.042 mmol, 35%) as a mixture of diastereomers.

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 9.17 (s, 1H), 8.76 (s, 1H), 8.60 (s, 1H), 7.32 – 7.14 (m, 5H), 4.82 – 4.68 (m, 1H), 3.31 – 3.01 (m, 3H), 1.52 – 1.13 (m, 3H), 0.87 – 0.74 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 171.9, 164.2, 148.8, 145.1, 144.6, 144.4, 137.8, 130.4, 129.4, 127.8, (55.3 and 54.9, diastereomers), (40.3 and 40.0, diastereomers), (38.9 and 38.7, diastereomers), (26.0 and 25.9, diastereomers), 23.6, (22.0 and 21.9, diastereomers).

HRMS (ESI, m/z): Calcd for $C_{19}H_{25}BN_4O_4Na$ $[M + Na]^+$ 407.1864; found 407.1870.

Ixazomib ((±)-5b)



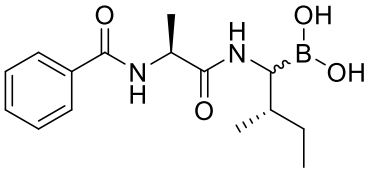
On 0.09 mmol scale, ixazomib ((±)-**5b**) was obtained after HPLC purification as a colorless solid (18.15 mg, 0.050 mmol, 56%).

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.55 (s, 1H), 7.45 (s, 2H), 3.94 (s, 2H), 3.06 (dd, *J* = 9.6, 5.4 Hz, 1H), 1.66 – 1.54 (m, 1H), 1.50 – 1.40 (m, 1H), 1.38 – 1.30 (m, 1H), 0.91 – 0.82 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 170.3, 167.4, 137.8, 133.5, 132.5, 132.2, 130.2, 130.0, 43.5, 40.4, 26.1, 23.6, 22.1 ppm.

HRMS (ESI, m/z): Calcd for $C_{14}H_{19}BCl_2N_2O_4Na$ $[M + Na]^+$ 383.0710; found 383.0712.

Bz-Ala-Ile-B(OH)$_2$ (5c)



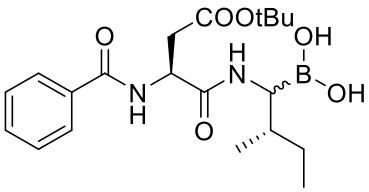
On 0.06 mmol scale, Bz-Ala-Ile-B(OH)$_2$ (**5c**) was obtained as a colorless solid after lyophilisation (7.23 mg, 0.024 mmol, 40%) as a mixture of diastereomers.

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.82 (d, *J* = 8.2 Hz, 2H), 7.54 (t, *J* = 7.4 Hz, 1H), 7.46 (t, *J* = 7.0 Hz, 2H), 4.54 – 4.46 (m, 1H), 3.13 (d, *J* = 5.4 Hz, 0.5H, diastereomer), 2.86 (d, *J* = 7.1 Hz, 0.5H, diastereomer), 1.68 – 1.57 (m, 1H), 1.40 (d, *J* = 7.1 Hz, 3H), 1.38 – 1.28 (m, 1H), 1.15 – 0.99 (m, 1H), 0.88 – 0.79 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ (174.80 and 174.78, diastereomers), (169.0 and 168.9, diastereomers), (134.7 and 134.6, diastereomers), (132.84 and 132.83, diastereomers), 129.5, 128.3, (50.6 and 50.4, diastereomers), (36.9 and 36.7, diastereomers), (27.9 and 27.4, diastereomers), (18.3 and 17.9, diastereomers), (17.20 and 17.16, diastereomers), (12.3 and 11.8, diastereomers) ppm.

HRMS (ESI, m/z): Calcd for $C_{15}H_{23}BN_2O_4Na$ $[M + Na]^+$ 329.1646; found 329.1670.

Bz-Asp(tBu)-Ile-B(OH)$_2$ (5d)



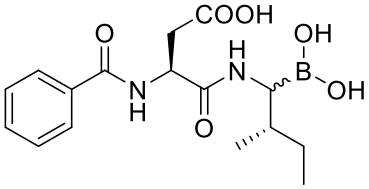
On 0.06 mmol scale, Bz-Asp(tBu)-Ile-B(OH)$_2$ (**5d**) was obtained as a colorless solid after lyophilisation (11.20 mg, 0.028 mmol, 47%) as a mixture of diastereomers.

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.84 – 7.75 (m, 2H), 7.55 (t, *J* = 7.1 Hz, 1H), 7.47 (t, *J* = 7.7 Hz, 2H), 4.89 – 4.80 (m, 1H), 3.14 (d, *J* = 5.2 Hz, 0.5H, diastereomer), 2.98 (d, *J* = 6.7 Hz, 0.5H, diastereomer), 2.87 – 2.64 (m, 2H), 1.67 – 1.55 (m, 1H), 1.39 – 1.36 (m, 9H), 1.35 – 1.28 (m, 1H), 1.13 – 0.99 (m, 1H), 0.86 – 0.78 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 172.1, 171.4, 168.9, 134.5, 133.0, 129.6, 128.3, 82.3, (51.5 and 51.3, diastereomers), (38.3 and 37.8, diastereomers), (36.94 and 36.86, diastereomers), 28.2, (27.9 and 27.3, diastereomers), (17.3 and 17.1, diastereomers), (12.3 and 11.9, diastereomers) ppm.

HRMS (ESI, m/z): Calcd for $C_{20}H_{31}BN_2O_6Na$ $[M + Na]^+$ 429.2171; found 429.2192.

Bz-Asp-Ile-B(OH)$_2$ (5e)



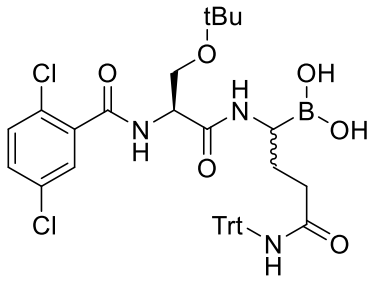
To a solution of **5d** in methylene chloride (3 mL), 2 mLtrifluoroacetic acid were added dropwise at 0°C under constant stirring and the solution was allowed to warm to room temperature. Upon completion, the solution was coevaporated with acetonitrile and the remaining residue was dissolved in acetonitrile/water and lyophilised. The crude product (9.39 mg) was purified by HPLC to obtain Bz-Asp-Ile-B(OH)$_2$ (**5e**) as a colorless solid (3.29 mg, 0.009 mmol, 34%).

^{1}H NMR (500 MHz, CD_3CN/D_2O 9:1) δ 7.81 – 7.75 (m, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.46 (t, *J* = 7.6 Hz, 2H), 4.92 – 4.81 (m, 1H), 3.07 (d, *J* = 5.5 Hz, 0.5H, diastereomer), 2.96 – 2.86 (m, 1.5H, diastereomer), 2.84 – 2.75 (m, 1H), 1.65 – 1.54 (m, 1H), 1.43 – 1.25 (m, 1H), 1.12 – 0.98 (m, 1H), 0.88 – 0.73 (m, 6H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 9:1) δ 174.2, 173.9, 172.6, 169.4, 134.3, 133.1, 129.6, (128.35 and 128.33, diastereomers), 51.2, 50.9, 36.7, 36.7, 36.6, 36.2, 27.9, 27.3, 17.2, 17.1, 12.2, 11.8 ppm.

HRMS (ESI, m/z): Calcd for $C_{16}H_{23}BN_2O_6Na$ $[M + Na]^+$ 373.1544; found 373.1542.

Bz(2,5-di-chloro)-Ser(tBu)-Gln(Trt)-B(OH)$_2$ (5f)



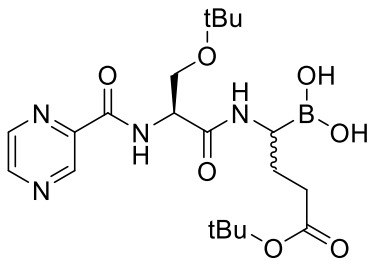
On 0.06 mmol scale, **5f** was obtained after lyophilisation as a colorless solid (19.73 mg, 0.028 mmol, 47%).

^{1}H NMR (300 MHz, CD_3CN/D_2O 9:1) δ 7.56 – 7.50 (m, 1H), 7.46 – 7.40 (m, 2H), 7.30 – 7.14 (m, 15H), 4.51 (q, *J* = 4.7 Hz, 1H), 3.79 – 3.70 (m, 1H), 3.67 – 3.56 (m, 1H), 3.11 – 2.96 (m, 1H), 2.45 – 2.19 (m, 2H), 1.89 – 1.63 (m, 2H), 1.15 (s, 9H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ (174.25 and 174.20, diastereomers), (171.33 and 171.25, diastereomers), (166.88 and 166.86, diastereomers), 145.8, 137.7, 133.5, 132.5, 132.2, 130.2, 130.1, 129.6, 128.6, 127.7, (74.8 and 74.7, diastereomers), 70.8, 62.3, (55.4 and 55.3, diastereomers) 35.3, (27.9 and 27.8, diastereomers) 27.6 ppm.

HRMS (ESI, m/z): Calcd for $C_{37}H_{40}BCl_2N_3O_6Na$ $[M + Na]^+$ 726.2286; found 726.2292.

Pyrazinoyl-Ser(tBu)-Glu(tBu)-B(OH)$_2$ (5g)



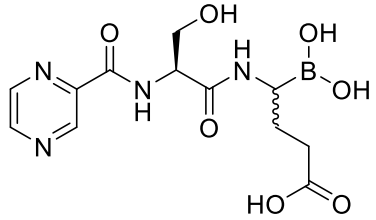
On 0.06 mmol scale, **5g** was obtained after lyophilisation as a colorless solid (16.59 mg, 0.037 mmol, 61%).

^{1}H NMR (300 MHz, CD_3CN/D_2O 9:1) δ 9.26 – 9.21 (m, 1H), 8.79 (d, *J* = 2.5 Hz, 1H), 8.68 – 8.62 (m, 1H), 4.58 – 4.49 (m, 1H), 3.87 – 3.77 (m, 1H), 3.68 – 3.56 (m, 1H), 3.11 – 2.94 (m, 1H), 2.34 – 2.10 (m, 2H), 1.88 – 1.63 (m, 2H), 1.43 – 1.31 (m, 9H), 1.17 (s, 9H) ppm.

^{13}C NMR (75 MHz, CD_3CN/D_2O 9:1) δ 174.4, 171.3, 164.4, 148.9, 145.1, 144.7, 144.5, 81.0, 74.9, 62.6, 54.4, 33.9, 28.3, 27.6, 26.8, 26.6 ppm.

HRMS (ESI, m/z): Calcd for $C_{20}H_{33}BN_4O_7Na$ $[M + Na]^+$ 475.2338; found 475.2347.

Pyrazinoyl-Ser-Glu-B(OH)$_2$ (5h)



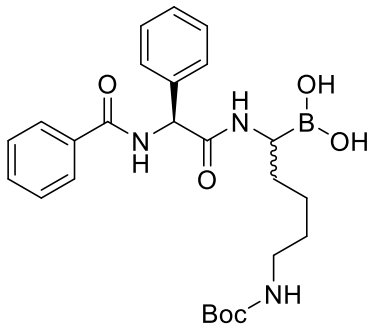
On 0.037 mmol scale, the compound was synthesised from **5g** by dissolving it in a solution of TFA in DCM (40%, v/v) and stirring at room temperature for 2 hours. After HPLC purification and lyophilisation, **5h** was obtained as a pale yellow solid as a mixture of anhydrides and diastereomers (9.14 mg, 0.027 mmol, 73%).

^{1}H NMR (500 MHz, CD_3OD/D_2O 9:1) δ 9.31 (s, 1H), 8.87 (s, 1H), 8.75 (s, 1H), 4.95 – 4.89 (m, 1H), 4.18 – 3.83 (m, 2H), 2.98 – 2.88 (m, 0.5H, diastereomer), 2.65 (q, *J* = 7.2 Hz, 0.5H, diastereomer), 2.44 – 2.37 (m, 1H), 2.36 – 2.23 (m, 1H), 1.89 – 1.67 (m, 2H) ppm.

^{13}C NMR (126 MHz, CD_3OD/D_2O 9:1) δ 177.0, 175.9, 165.8, 165.5, 149.0, 145.7, 144.9, 62.3 62.2, 61.8, 61.7, 53.8, 53.6, 53.5, 32.6, 29.1, 29.1, 27.0, 25.5 ppm.

HRMS (ESI, m/z): Calcd for $C_{12}H_{15}BN_4O_6Na$ $[M + Na]^+$ 345.0990; found 345.0970.

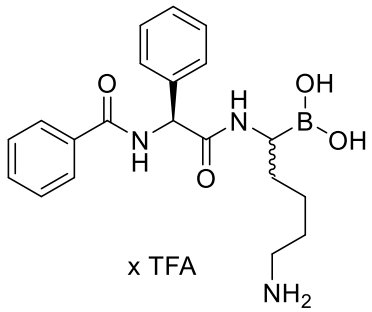
Bz-Phg-Lys(Boc)-B(OH)$_2$ (5i)



On 0.06 mmol scale, Bz-Phg-Lys(Boc)-B(OH)$_2$ (**5i**) was obtained as a colorless solid (13.67 mg, 0.028 mmol, 47%) that was directly used in the next step.

HRMS (ESI, m/z): Calcd for $C_{25}H_{34}BN_3O_6Na$ $[M + Na]^+$ 506.2437; found 506.2458.

Bz-Phg-Lys-B(OH)$_2$ × TFA (5j)



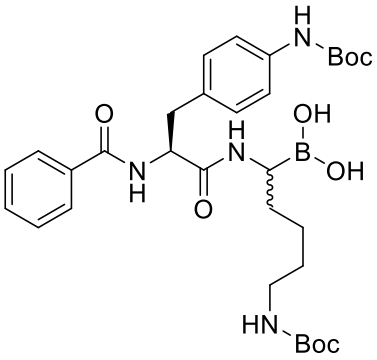
Compound **5i** (12.50 mg, 0.026 mmol, 1.0 eq) was stirred in a solution of acetonitrile/TFA/H_2O (7:2:1, v/v, 2 mL) at ambient temperature for 2 hours. After HPLC purification and lyophilisation, Bz-Phg-Lys-B(OH)$_2$ × TFA (**5j**) was obtained as a colorless solid (5.72 mg, 0.015 mmol, 57%) as a mixture of diastereomers.

^{1}H NMR (500 MHz, CD_3CN/D_2O 5:1) δ 7.83 (d, *J* = 7.2 Hz, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.52 – 7.43 (m, 4H), 7.42 – 7.32 (m, 3H), 5.59 – 5.53 (m, 1H), 2.98 (dd, *J* = 8.6, 5.9 Hz, 1H), 2.86 – 2.69 (m, 2H), 1.63 – 1.38 (m, 4H), 1.32 – 1.06 (m, 2H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 5:1) δ (172.1 and 172.0, diastereomers), 168.8 and 168.7, diastereomers), (138.5 and 138.3, diastereomers), 134.4, 133.0, 129.8, 129.6, 129.4, 128.8, 128.7, (128.5 and 128.4, diastereomers), (58.73 and 58.65, diastereomers), (40.3 and 40.2, diastereomers), (30.55 and 30.52, diastereomers), (27.3 and 27.2, diastereomers), (24.3 and 24.1, diastereomers) ppm.

HRMS (ESI, m/z): Calcd for $C_{20}H_{25}BN_3O_3$ $[M - H_2O + H]^+$ 366.1987; found 366.1989.

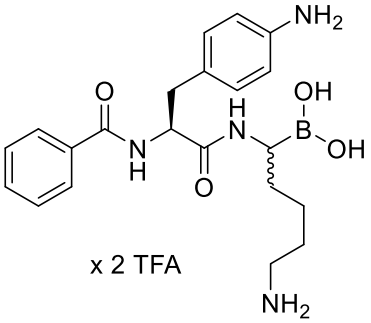
Bz-Phe(4-NHBoc)-Lys(Boc)-B(OH)$_2$ (5k)



On 0.06 mmol scale, Bz-Phe(4-NHBoc)-Lys(Boc)-B(OH)$_2$ (**5k**) was obtained as a colorless solid (21.32 mg, 0.035 mmol, 58%) that was directly used in the next step.

HRMS (ESI, m/z): Calcd for $C_{25}H_{34}BN_3O_6Na$ $[M + Na]^+$ 635.3228; found 635.3238.

Bz-Phe(4-NH$_2$)-Lys-B(OH)$_2$ × 2 TFA (5l)



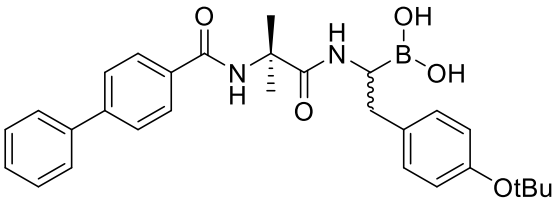
Compound **5k** (20.50 mg, 0.033 mmol, 1.0 eq) was stirred in a solution of acetonitrile/TFA/H_2O (7:2:1, v/v, 2 mL) at ambient temperature for 2 hours. After HPLC purification and lyophilisation, Bz-Phe(4-NH_2)-Lys-B(OH)$_2$ × 2 TFA (**5l**) was obtained as a pale yellow solid (12.96 mg, 0.020 mmol, 61%) as a mixture of diastereomers.

^{1}H NMR (500 MHz, CD_3CN/D_2O 2:1) δ 7.72 (d, *J* = 7.3 Hz, 2H), 7.57 – 7.49 (m, 1H), 7.44 (t, *J* = 7.8 Hz, 2H), 7.41 – 7.33 (m, 2H), 7.28 (d, *J* = 6.3 Hz, 2H), 4.81 – 4.66 (m, 1H), 3.30 – 2.67 (m, 5H), 1.63 – 1.33 (m, 3H), 1.33 – 0.88 (m, 3H) ppm.

^{13}C NMR (126 MHz, CD_3CN/D_2O 2:1) δ (173.5 and 173.4, diastereomers), (169.5 and 169.4, diastereomers), 139.1, 134.3, 133.1, 131.9, 130.1, 129.6, 128.4, 124.1, (55.5 and 55.3, diastereomers) 40.2, 37.7, (30.5 and 30.3, diastereomers), 27.3, 24.3 ppm.

HRMS (ESI, m/z): Calcd for $C_{21}H_{28}BN_4O_3$ $[M - H_2O + H]^+$ 395.2253; found 395.2258.

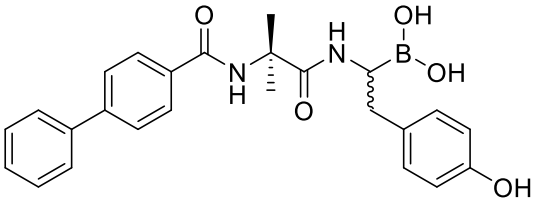
Bz(4-Ph)-Aib-Tyr(tBu)-B(OH)$_2$ (5m)



On 0.06 mmol scale, Bz(4-Ph)-Aib-Tyr(tBu)-B(OH)$_2$ (**5m**) was obtained as colorless solid (16.6 mg, 0.033 mmol, 55%) that was directly used in the next step.

HRMS (ESI, m/z): Calcd for $C_{29}H_{35}BN_2O_5Na$ $[M + Na]^+$ 525.2536; found 525.2531.

Bz(4-Ph)-Aib-Tyr-B(OH)$_2$ (5n)



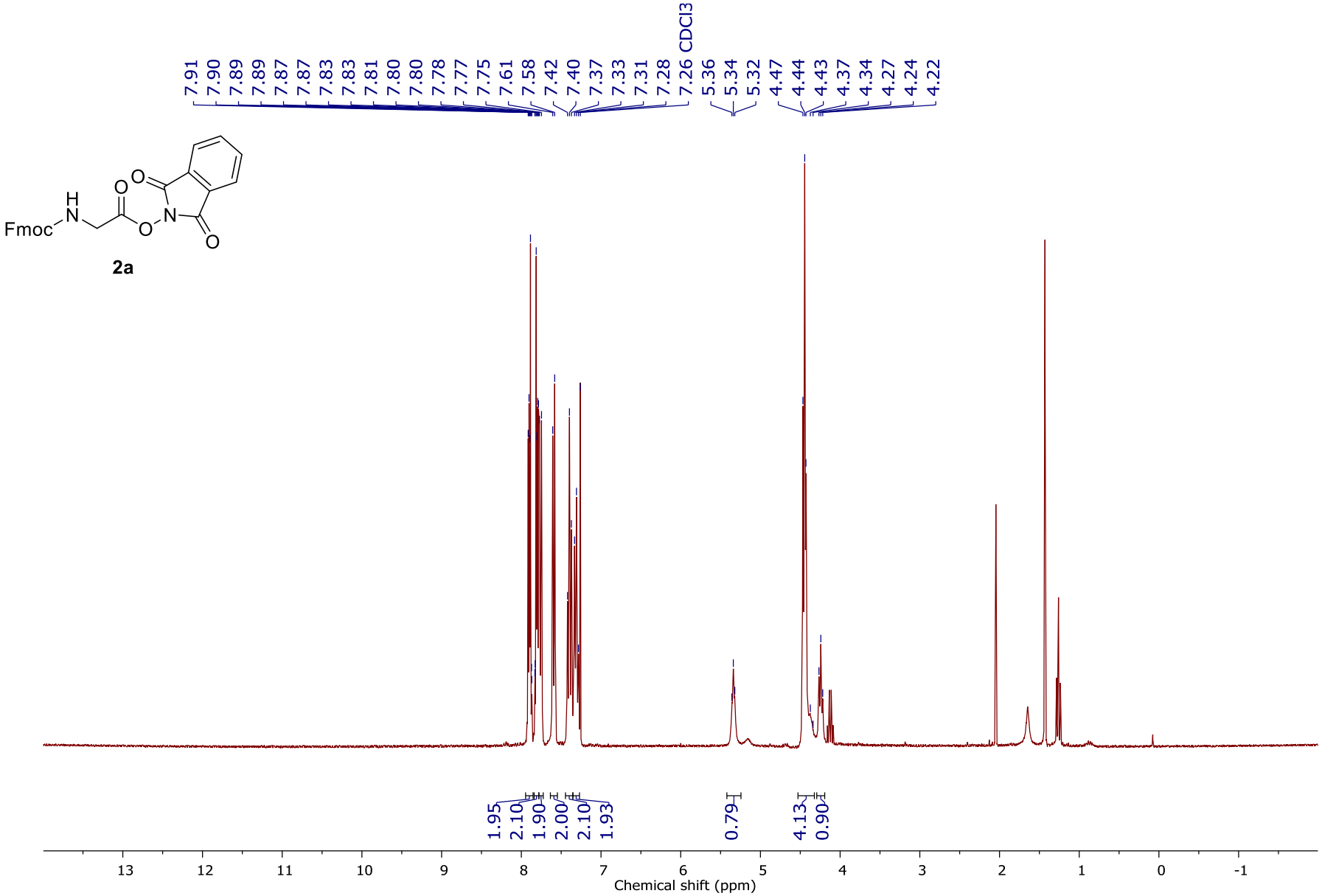
Compound **5m** (16.5 mg, 0.033 mmol, 1.0 eq) was stirred in a solution of acetonitrile/TFA/H_2O (7:2:1, v/v, 2 mL) at ambient temperature for 2 hours. After HPLC purification and lyophilisation, Bz(4-Ph)-Aib-Tyr-B(OH)$_2$ (**5n**) was obtained as a colorless solid (5.52 mg, 0.012 mmol, 38%) containing small fractions of anhydrides.

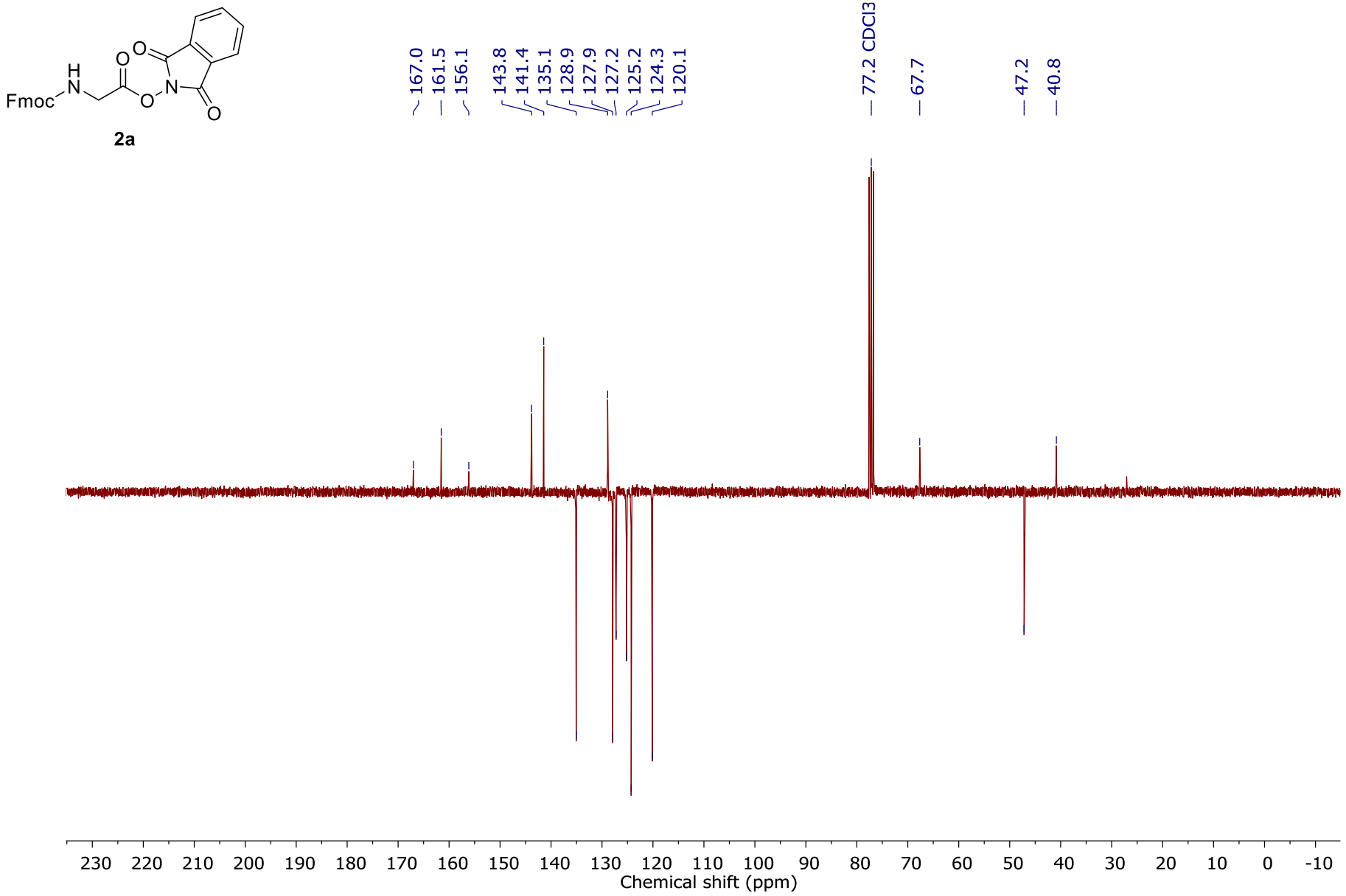
^{1}H NMR (500 MHz, CD_3CN/D_2O 3:1) δ 7.86 (d, *J* = 8.4 Hz, 2H), 7.73 (d, *J* = 8.5 Hz, 2H), 7.69 (d, *J* = 7.3 Hz, 2H), 7.48 (t, *J* = 7.6 Hz, 2H), 7.40 (t, *J* = 7.3 Hz, 1H), 6.96 (d, *J* = 8.4 Hz, 2H), 6.58 (d, *J* = 8.4 Hz, 2H), 2.92 (dd, *J* = 10.4, 4.8 Hz, 1H), 2.75 (dd, *J* = 14.1, 4.9 Hz, 1H), 2.58 (dd, *J* = 13.9, 10.5 Hz, 1H), 1.47 (s, 3H), 1.43 (s, 3H) ppm.

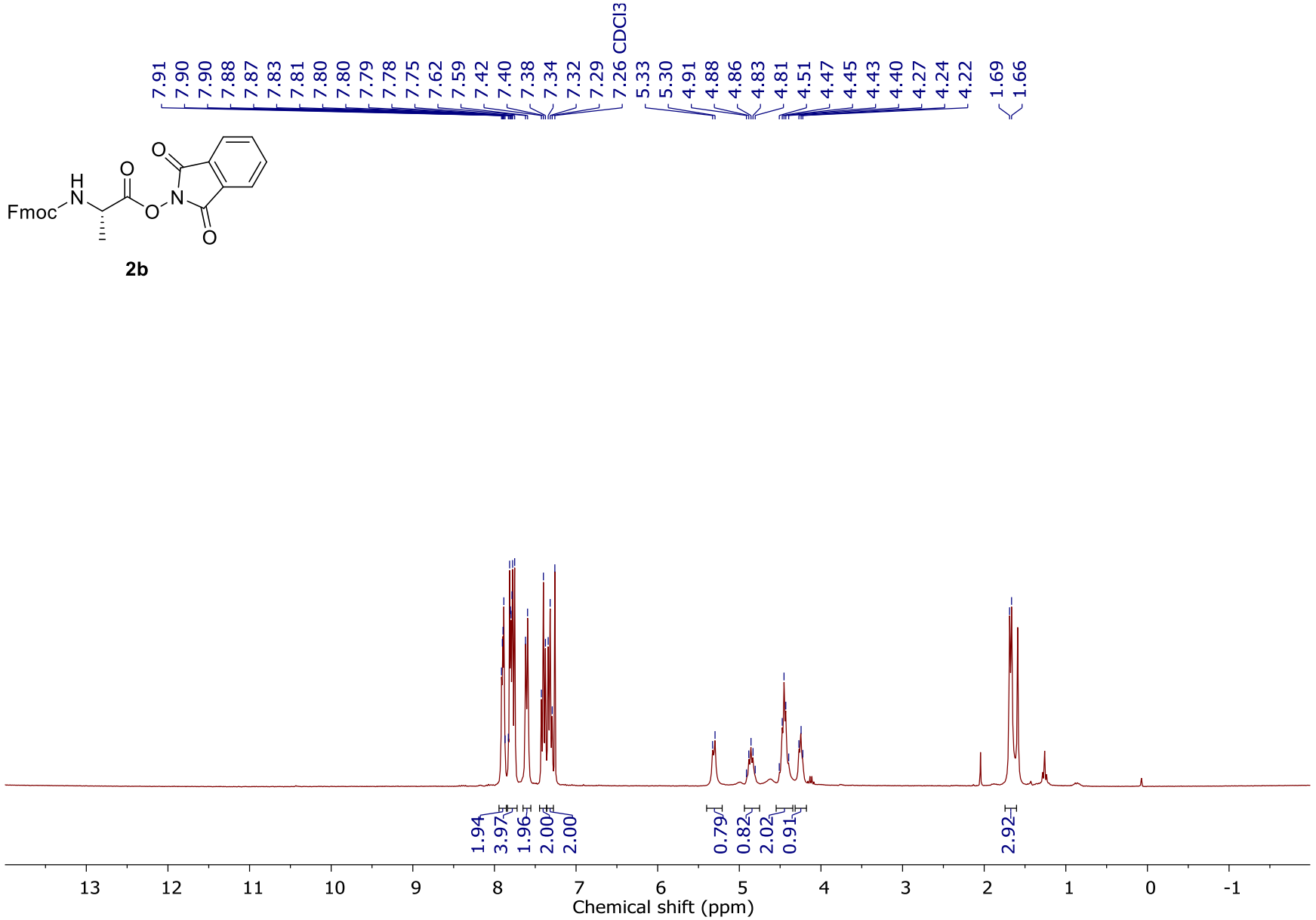
^{13}C NMR (126 MHz, CD_3CN/D_2O 3:1) δ 178.0, 168.8, 155.8, 145.2, 140.6, 133.4, 132.5, 131.0, 130.1, 129.22, 129.20, 128.1, 127.9, 115.9, 56.7, 36.1, 25.7, 25.0 ppm (Aib carbonyl at 178.0 ppm identified *via* HMBC).

HRMS (ESI, m/z): Calcd for $C_{25}H_{26}BN_2O_4$ $[M - H_2O + H]^+$ 429.1985; found 429.1984.

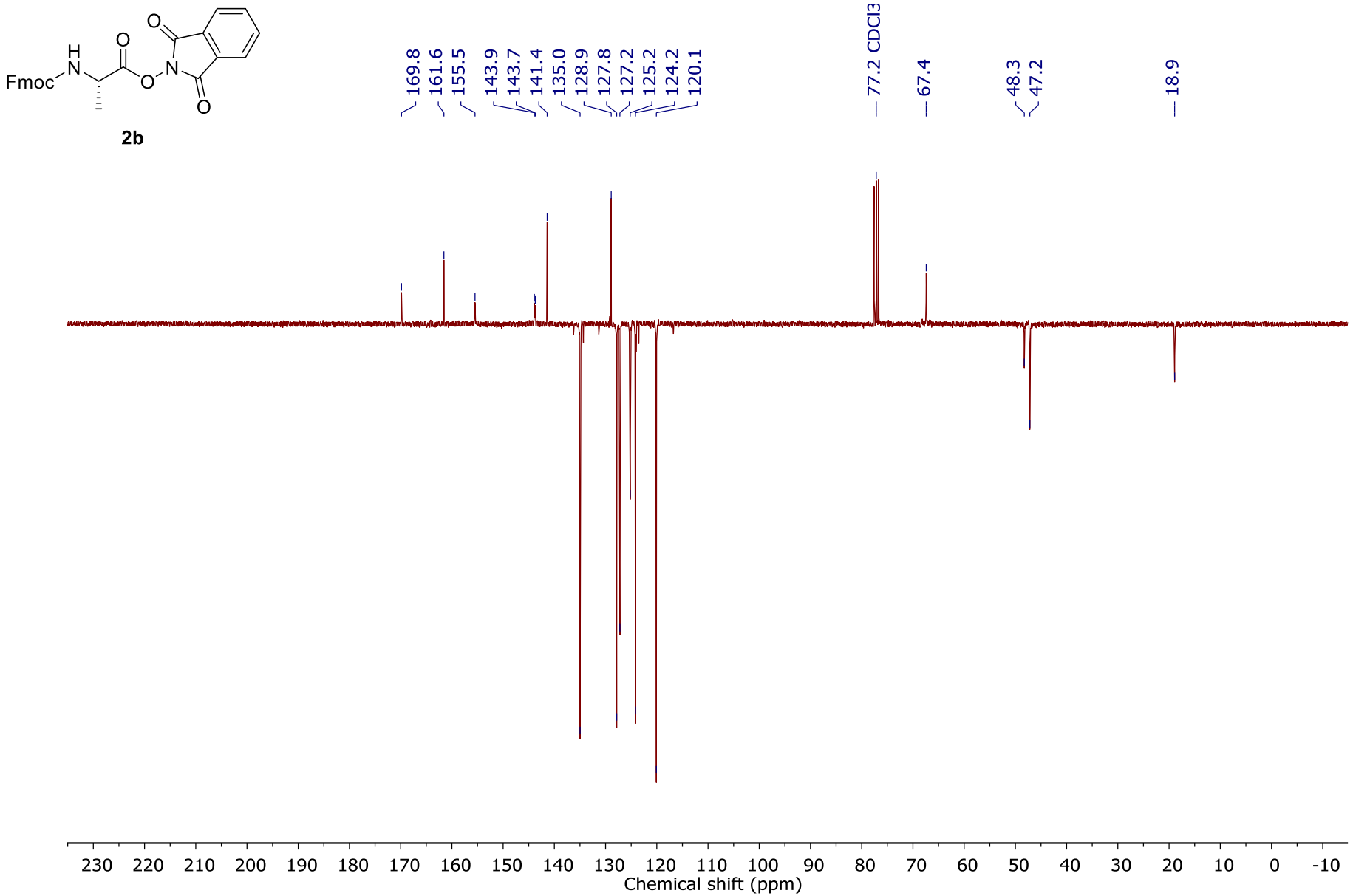
NMR spectra of NHPI esters

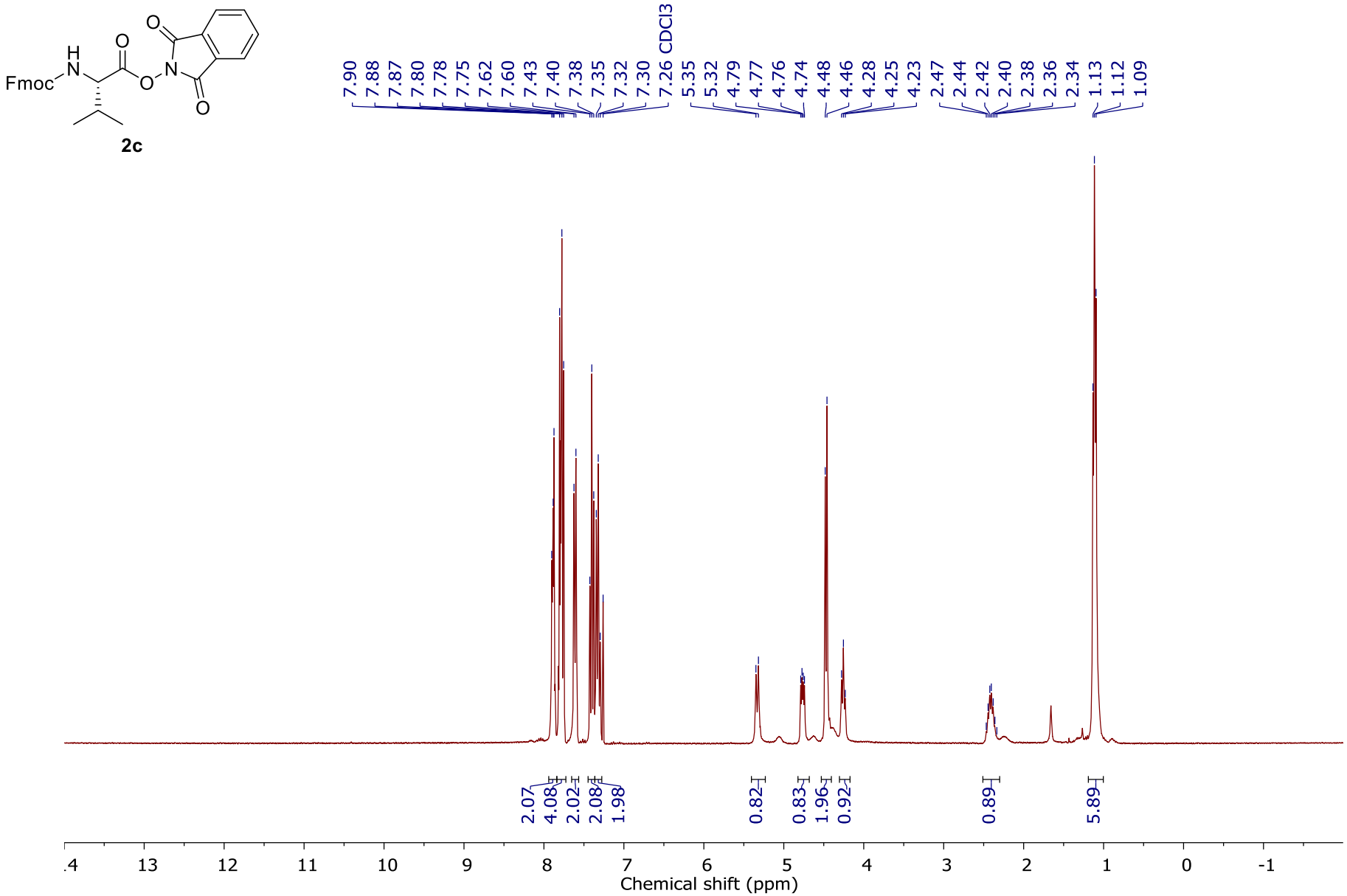

7.91
7.90
7.89
7.89
7.87
7.87
7.83
7.83
7.81
7.80
7.80
7.78
7.77
7.75
7.61
7.58
7.42
7.40
7.37
7.33
7.31
7.28
7.26 CDCl3
5.36
5.34
5.32
4.47
4.44
4.43
4.37
4.34
4.27
4.24
4.22
Fmoc
H
N
O
O
O
N
O
O
2a
1.95
2.10
1.90
2.00
2.10
1.93
0.79
4.13
0.90
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

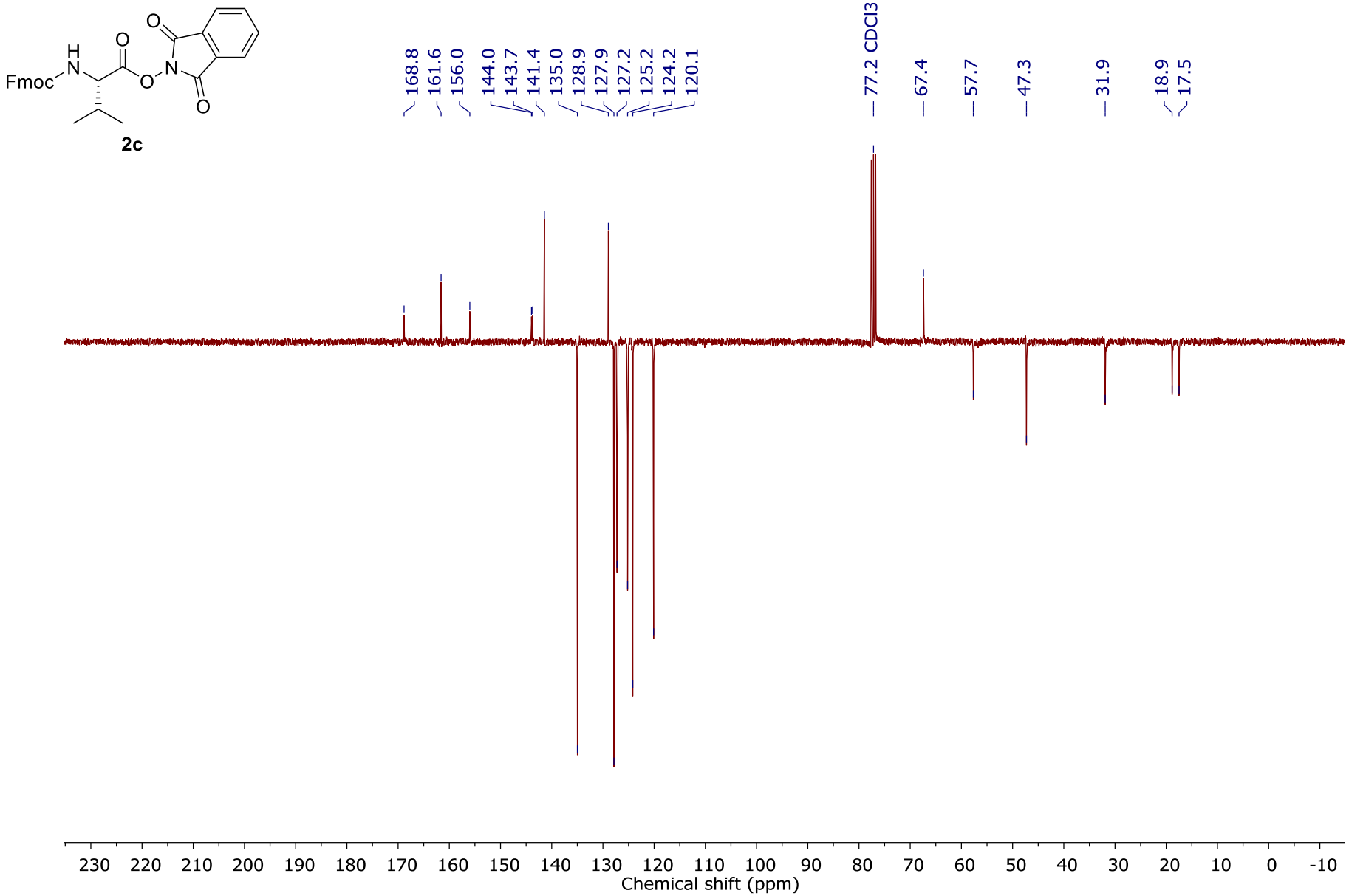

Fmoc
H
N
O
O
O
N
O
2a
167.0
161.5
156.1
143.8
141.4
135.1
128.9
127.9
127.2
125.2
124.3
120.1
77.2 CDCl3
67.7
47.2
40.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

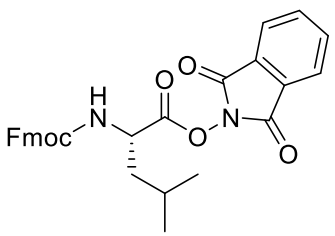

7.91
7.90
7.90
7.88
7.87
7.83
7.81
7.80
7.80
7.79
7.78
7.75
7.62
7.59
7.42
7.40
7.38
7.34
7.32
7.29
7.26 CDCl3
5.33
5.30
4.91
4.88
4.86
4.83
4.81
4.51
4.47
4.45
4.43
4.40
4.27
4.24
4.22
1.69
1.66
Fmoc
H
N
O
O
O
N
O
O
1.94
3.97
1.96
2.00
2.00
0.79
0.82
2.02
0.91
2.92
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

2b

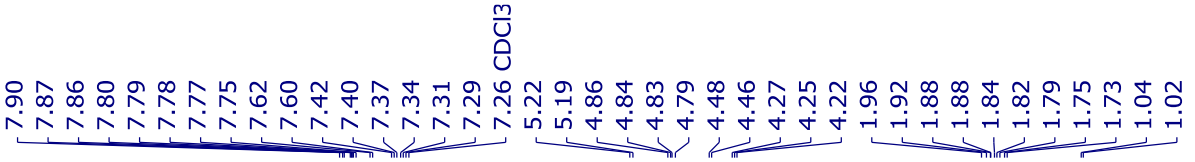

Fmoc
H
N
O
O
O
N
O
2b
169.8
161.6
155.5
143.9
143.7
141.4
135.0
128.9
127.8
127.2
125.2
124.2
120.1
77.2 CDCl3
67.4
48.3
47.2
18.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

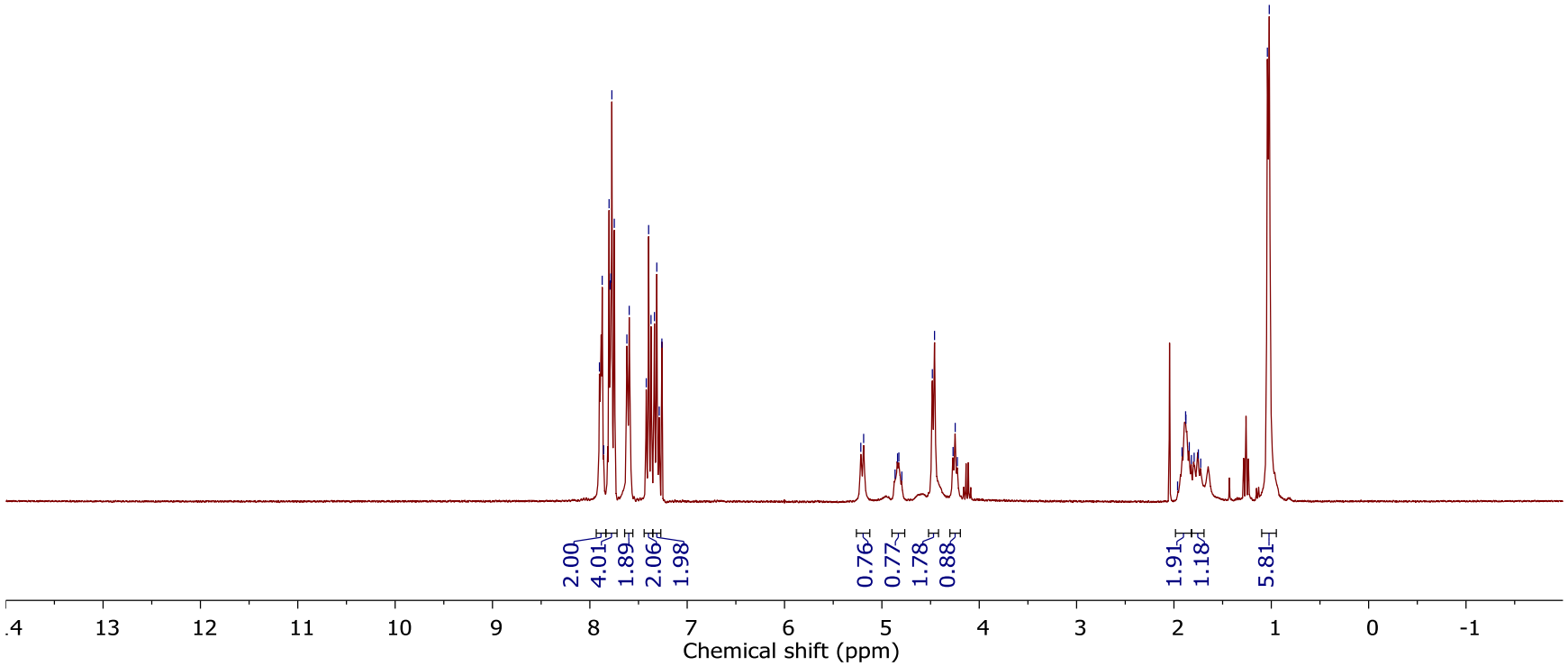

Fmoc
2c
7.90
7.88
7.87
7.80
7.78
7.75
7.62
7.60
7.43
7.40
7.38
7.35
7.32
7.30
7.26 CDCl3
5.35
5.32
4.79
4.77
4.76
4.74
4.48
4.46
4.28
4.25
4.23
2.47
2.44
2.42
2.40
2.38
2.36
2.34
1.13
1.12
1.09
2.07
4.08
2.02
2.08
1.98
0.82
0.83
1.96
0.92
0.89
5.89
Chemical shift (ppm)

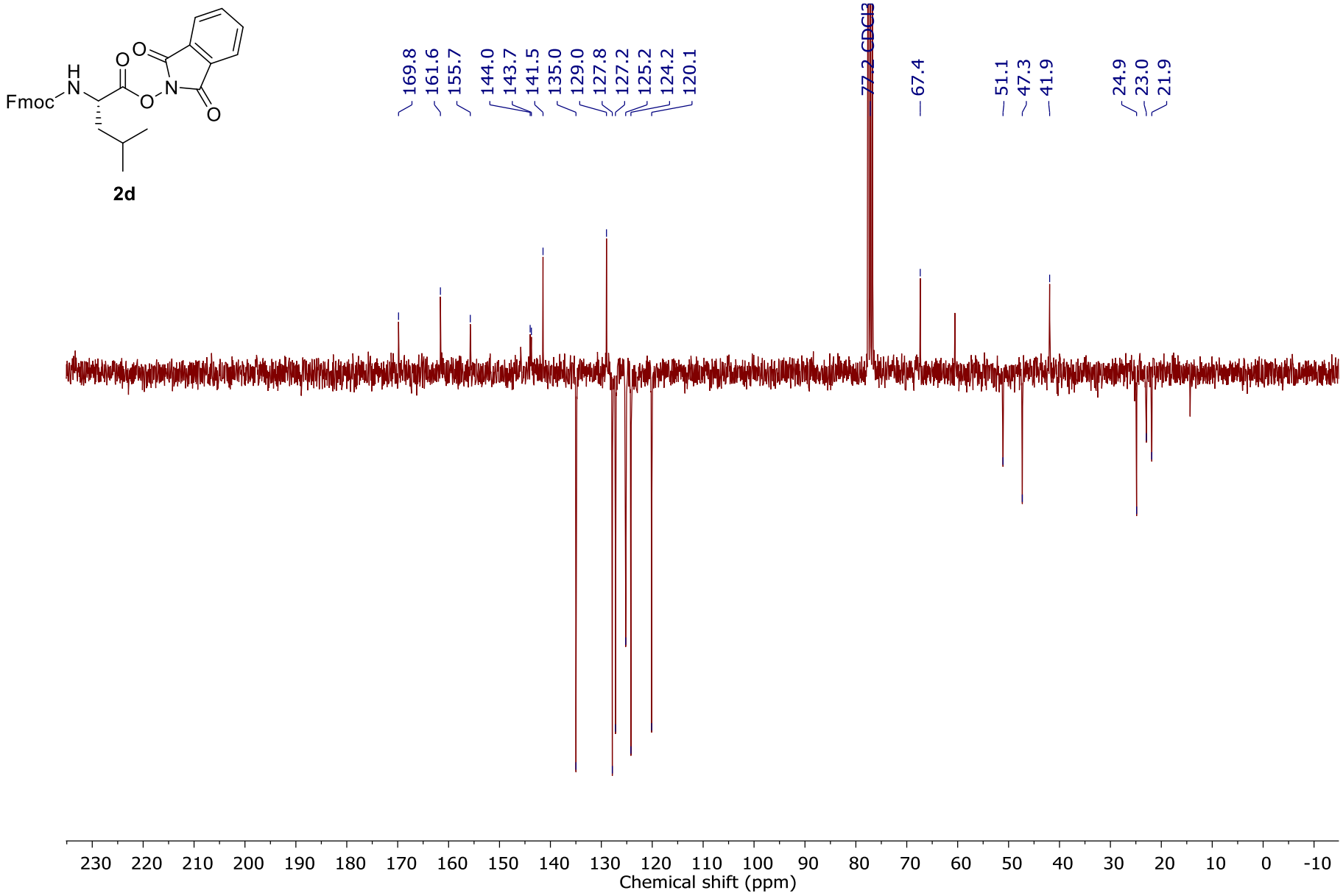

Fmoc
H
N
O
O
O
N
O
O
2c
168.8
161.6
156.0
144.0
143.7
141.4
135.0
128.9
127.9
127.2
125.2
124.2
120.1
77.2 CDCl3
67.4
57.7
47.3
31.9
18.9
17.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

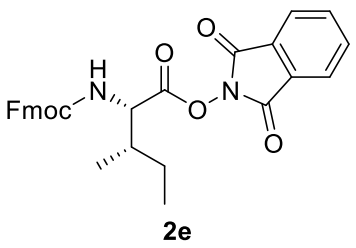

Fmoc
H
N
O
O
O
N
O

2d


7.90
7.87
7.86
7.80
7.79
7.78
7.77
7.75
7.62
7.60
7.42
7.40
7.37
7.34
7.31
7.29
7.26 CDCl3
5.22
5.19
4.86
4.84
4.83
4.79
4.48
4.46
4.27
4.25
4.22
1.96
1.92
1.88
1.88
1.84
1.82
1.79
1.75
1.73
1.04
1.02

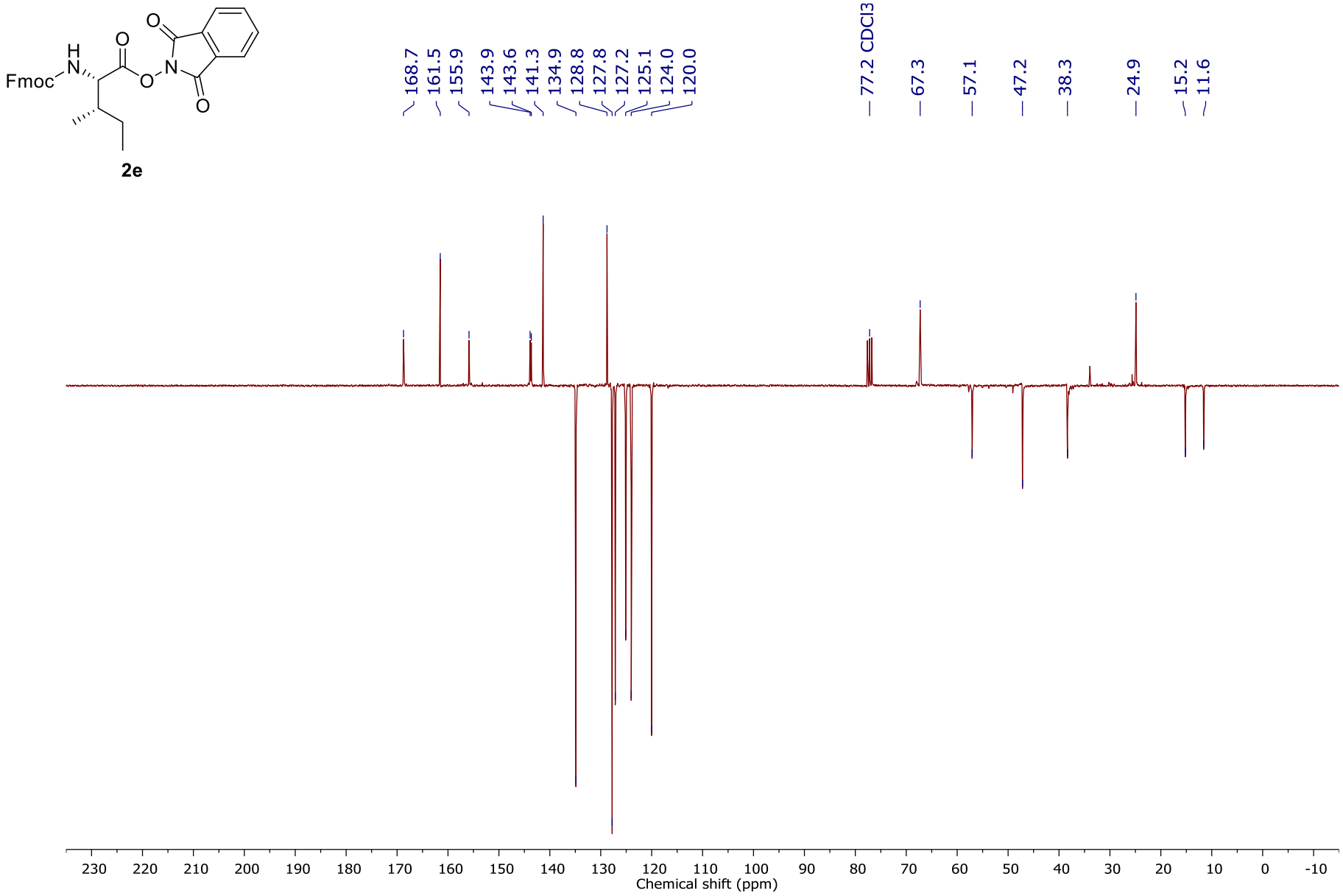

2.00
4.01
1.89
2.06
1.98
0.76
0.77
1.78
0.88
1.91
1.18
5.81
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

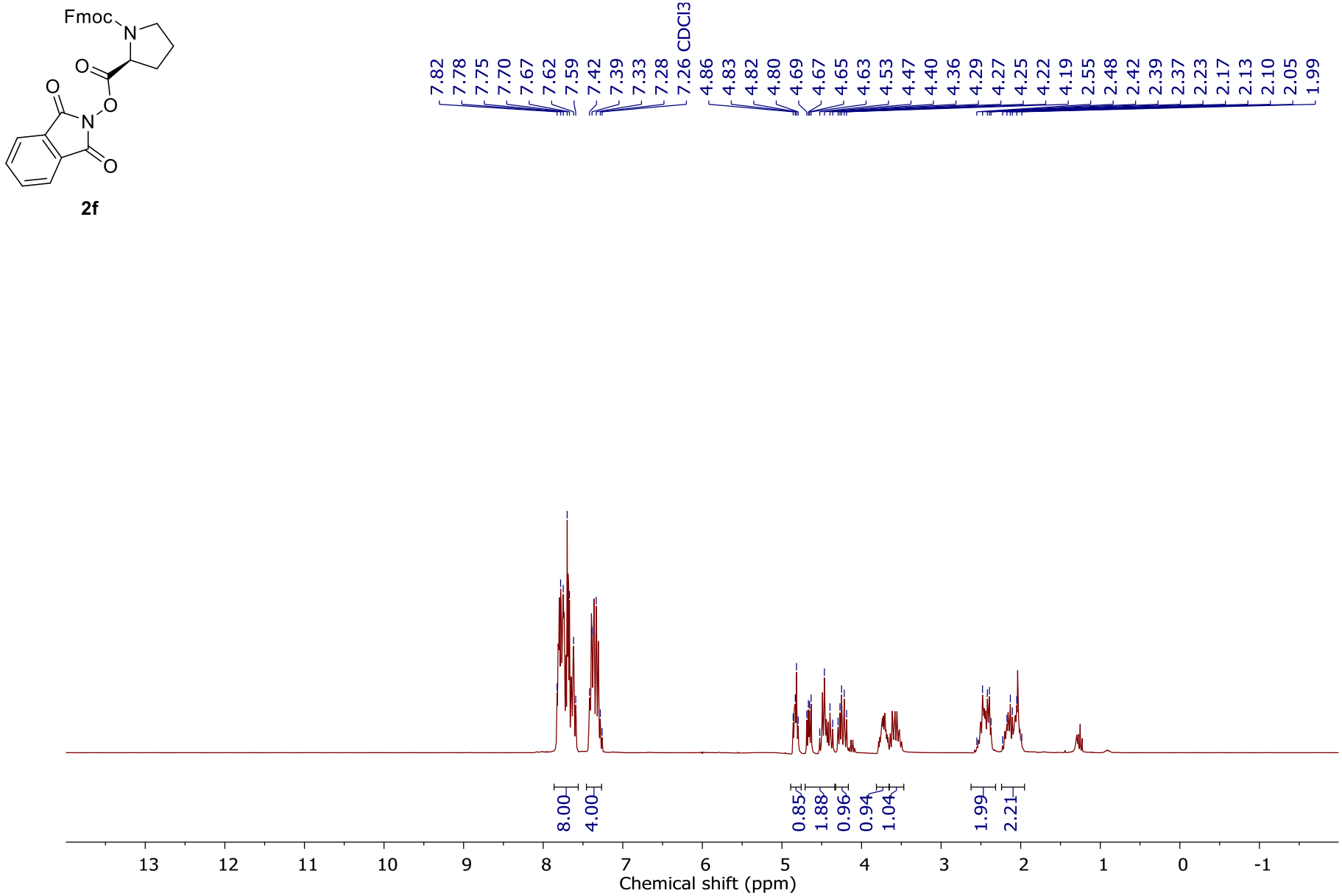

Fmoc
H
N
O
O
O
N
O
2d
169.8
161.6
155.7
144.0
143.7
141.5
135.0
129.0
127.8
127.2
125.2
124.2
120.1
77.2 CDCl3
67.4
51.1
47.3
41.9
24.9
23.0
21.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

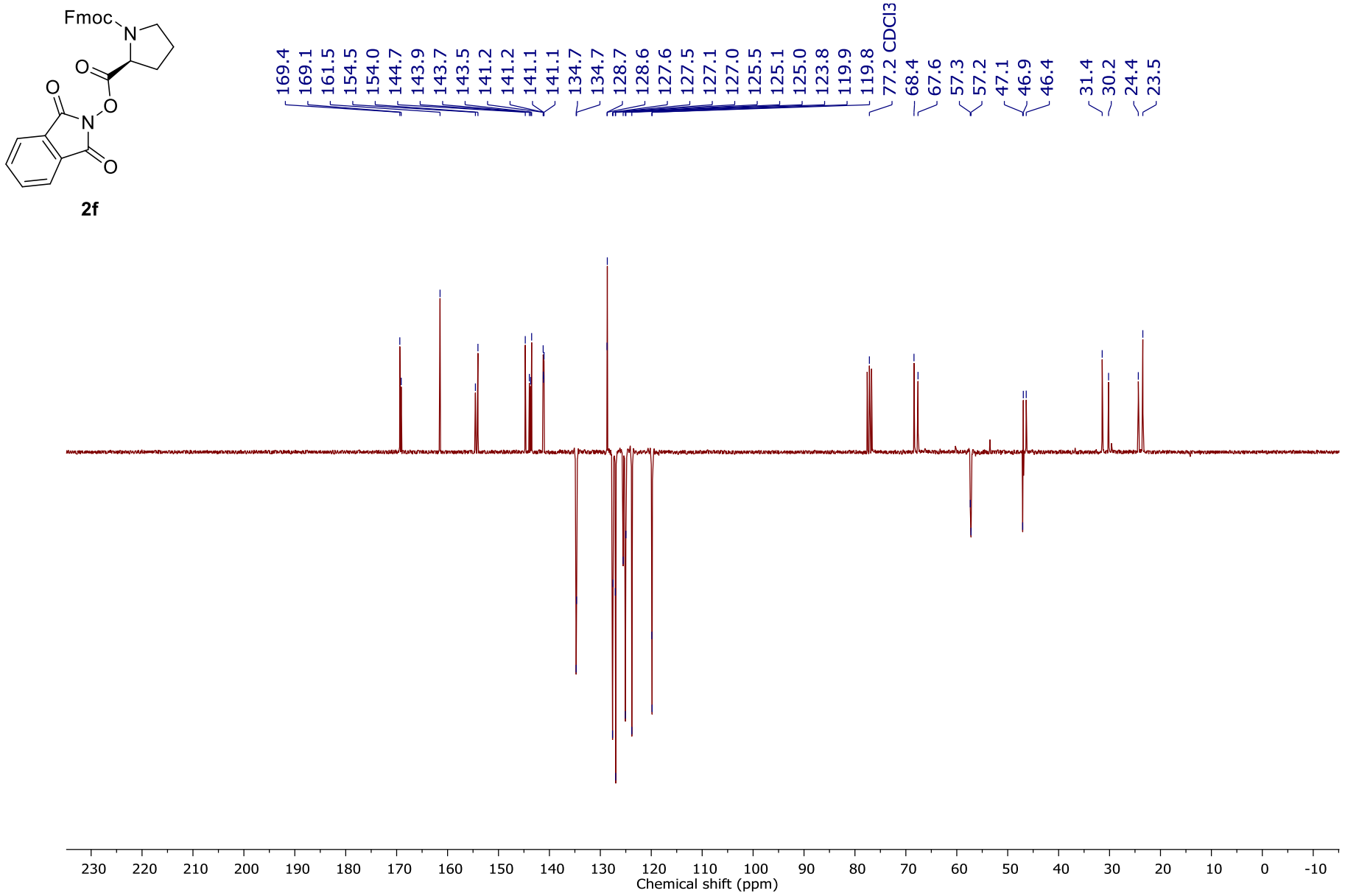

Fmoc
H
N
O
O
N
O
O
O

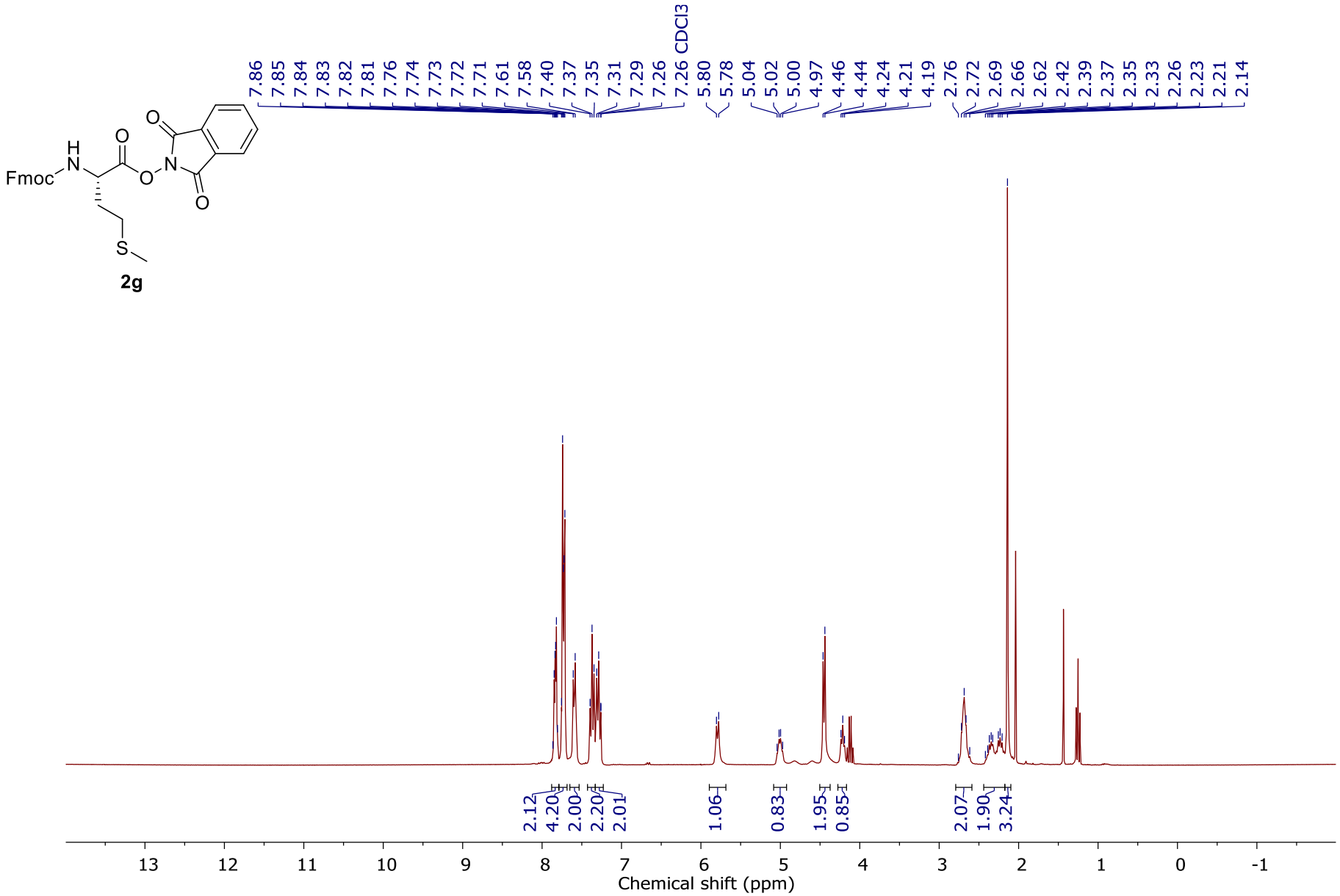
2e

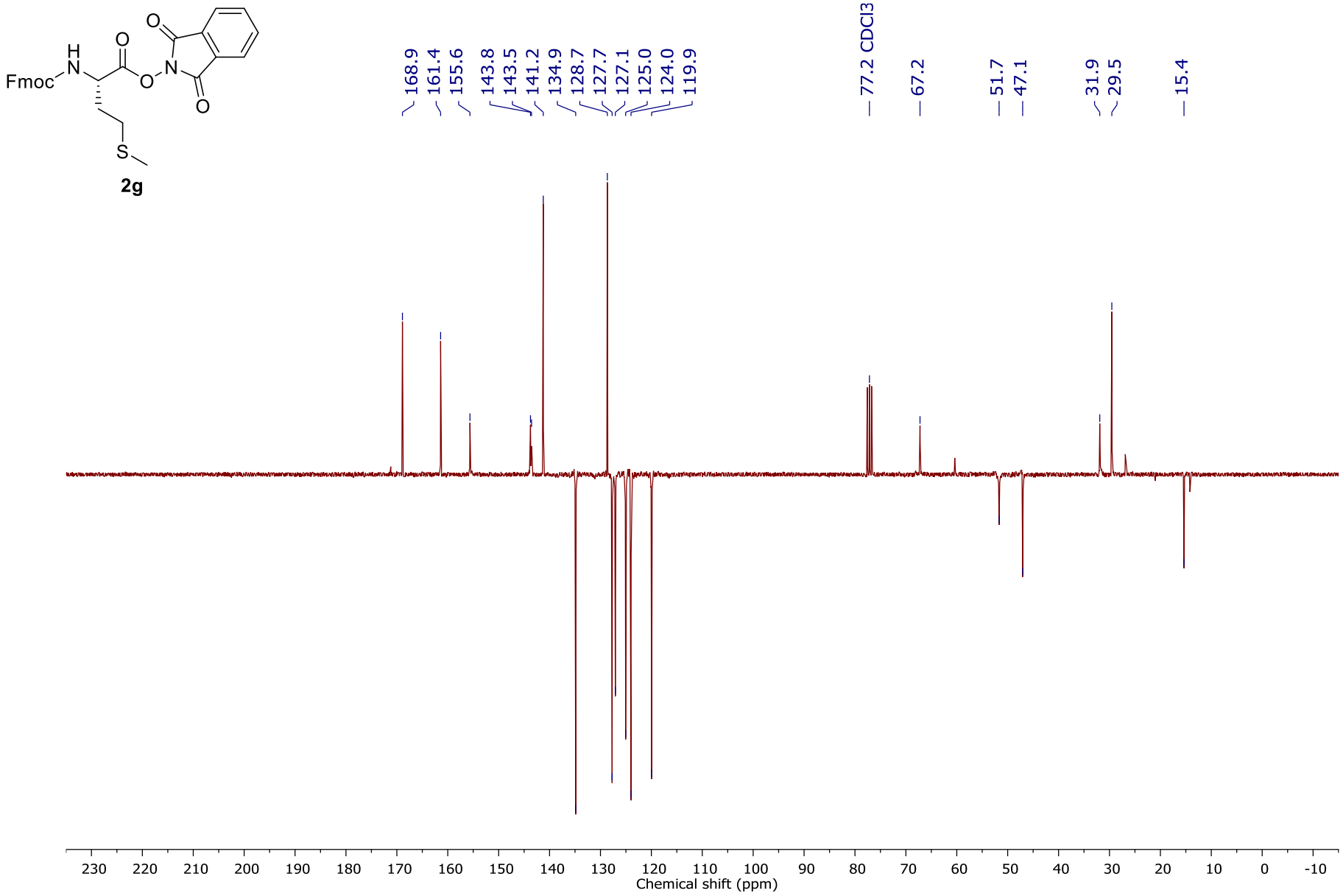
7.86
7.84
7.83
7.76
7.73
7.71
7.62
7.60
7.41
7.39
7.36
7.33
7.31
7.28
7.26 CDCl3
5.55
5.53
4.83
4.82
4.80
4.79
4.45
4.25
4.23
4.21
2.14
2.10
2.06
1.75
1.73
1.69
1.62
1.40
1.38
1.33
1.30
1.28
1.13
1.11
1.06
1.04
1.01
2.00
4.04
2.01
2.08
1.95
0.92
0.70
1.76
0.87
1.03
1.28
1.36
2.93
3.00
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-
Chemical shift (ppm)

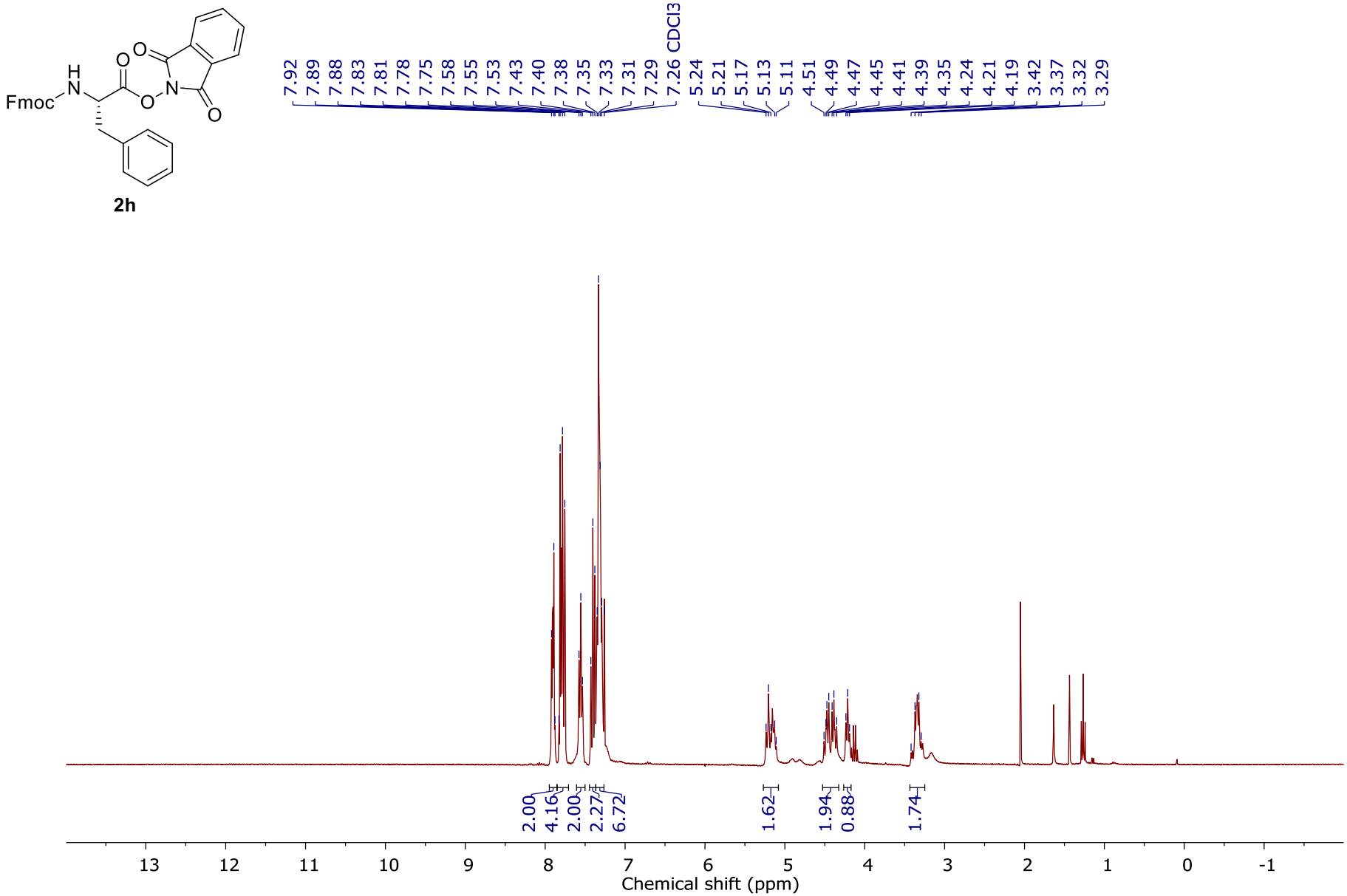

Fmoc
H
N
O
O
N
O
O
2e
168.7
161.5
155.9
143.9
143.6
141.3
134.9
128.8
127.8
127.2
125.1
124.0
120.0
77.2 CDCl3
67.3
57.1
47.2
38.3
24.9
15.2
11.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

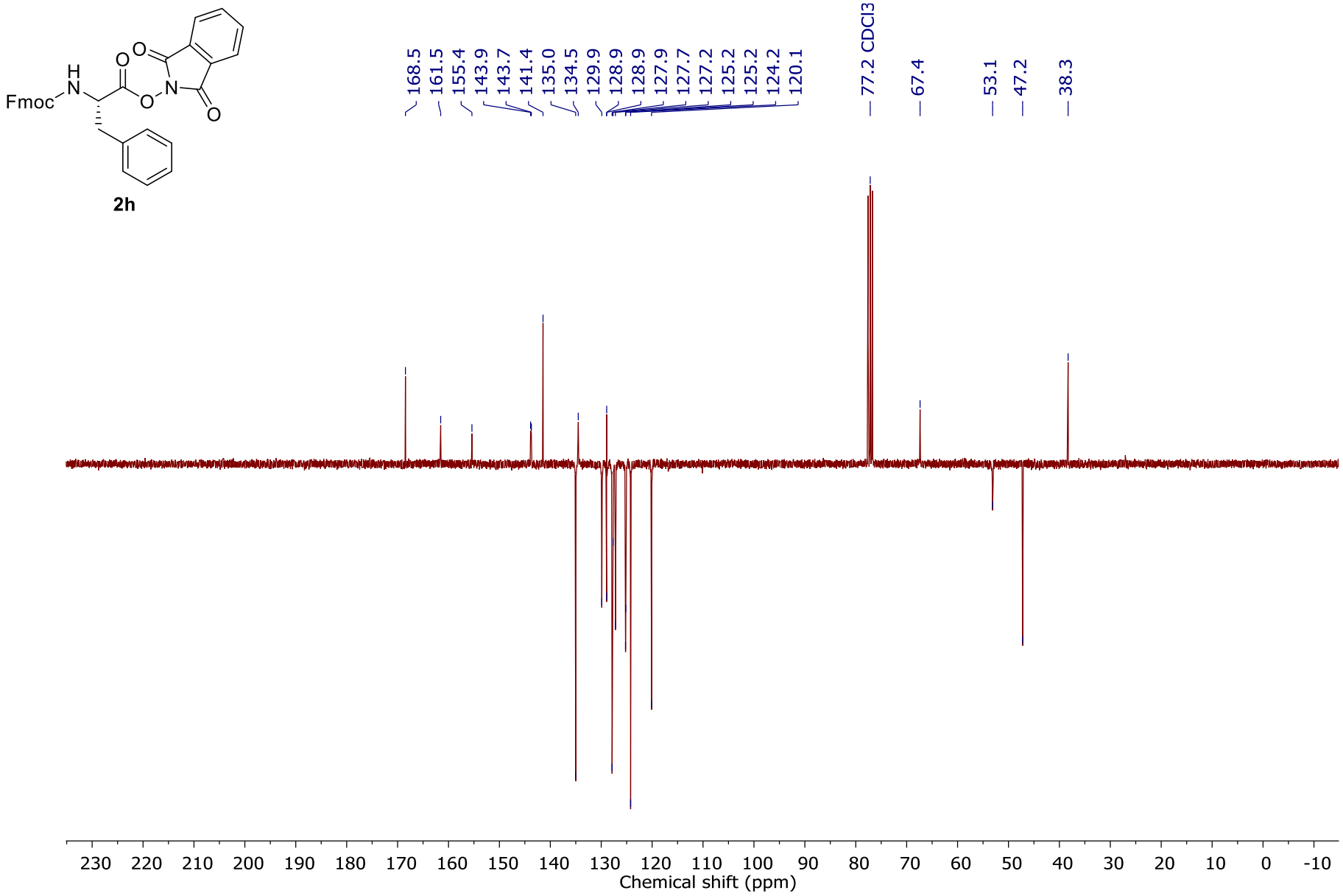

Fmoc
N
O
O
N
O
O
O
2f
7.82
7.78
7.75
7.70
7.67
7.62
7.59
7.42
7.39
7.33
7.28
7.26 CDCl3
4.86
4.83
4.82
4.80
4.69
4.67
4.65
4.63
4.53
4.47
4.40
4.36
4.29
4.27
4.25
4.22
4.19
2.55
2.48
2.42
2.39
2.37
2.23
2.17
2.13
2.10
2.05
1.99
8.00
4.00
0.85
1.88
0.96
0.94
1.04
1.99
2.21
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

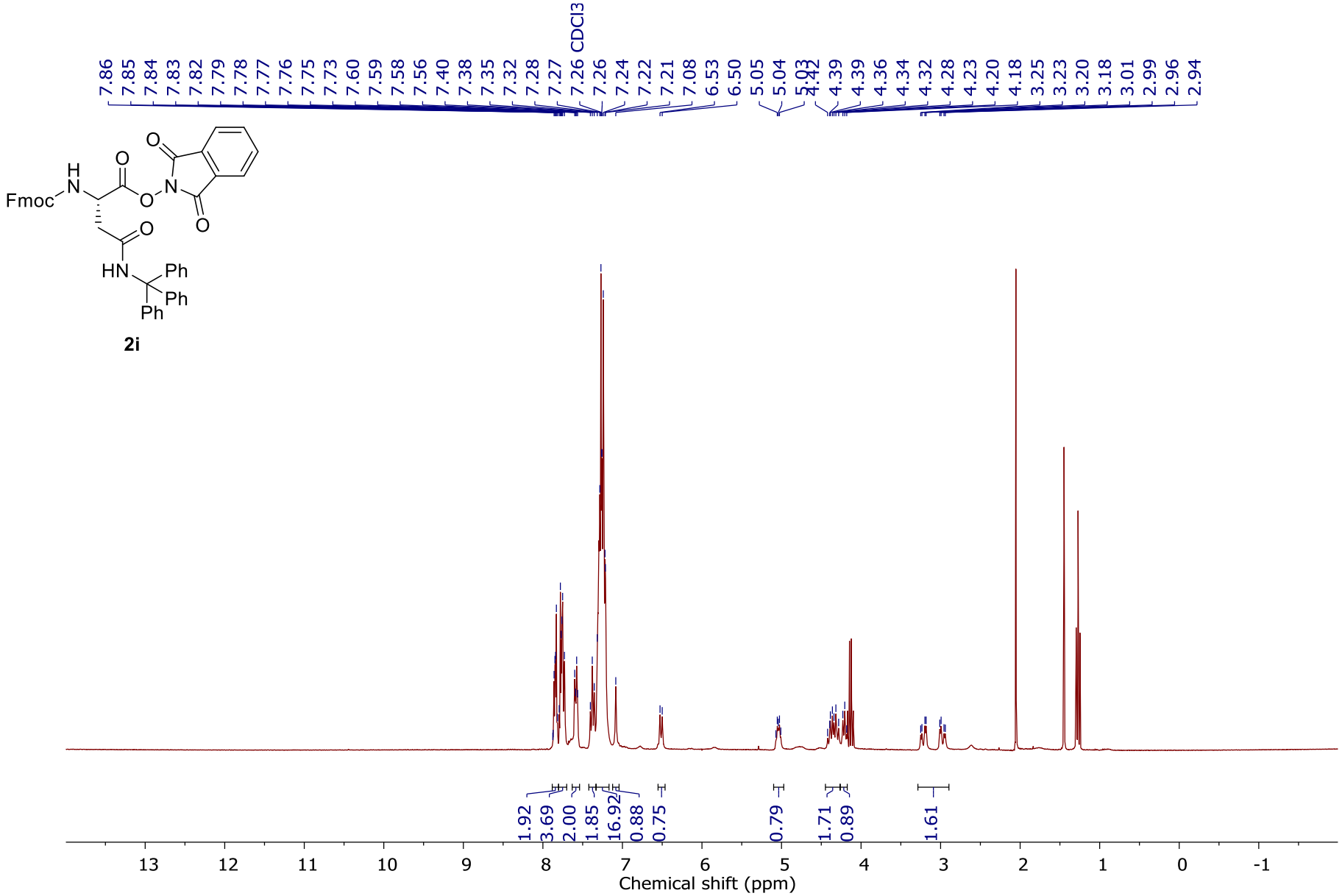

Fmoc
N
O
O
N
O
O
O
2f
169.4
169.1
161.5
154.5
154.0
144.7
143.9
143.7
143.5
141.2
141.2
141.1
141.1
134.7
134.7
128.7
128.6
127.6
127.5
127.1
127.0
125.5
125.1
125.0
123.8
119.9
119.8
77.2 CDCl3
68.4
67.6
57.3
57.2
47.1
46.9
46.4
31.4
30.2
24.4
23.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

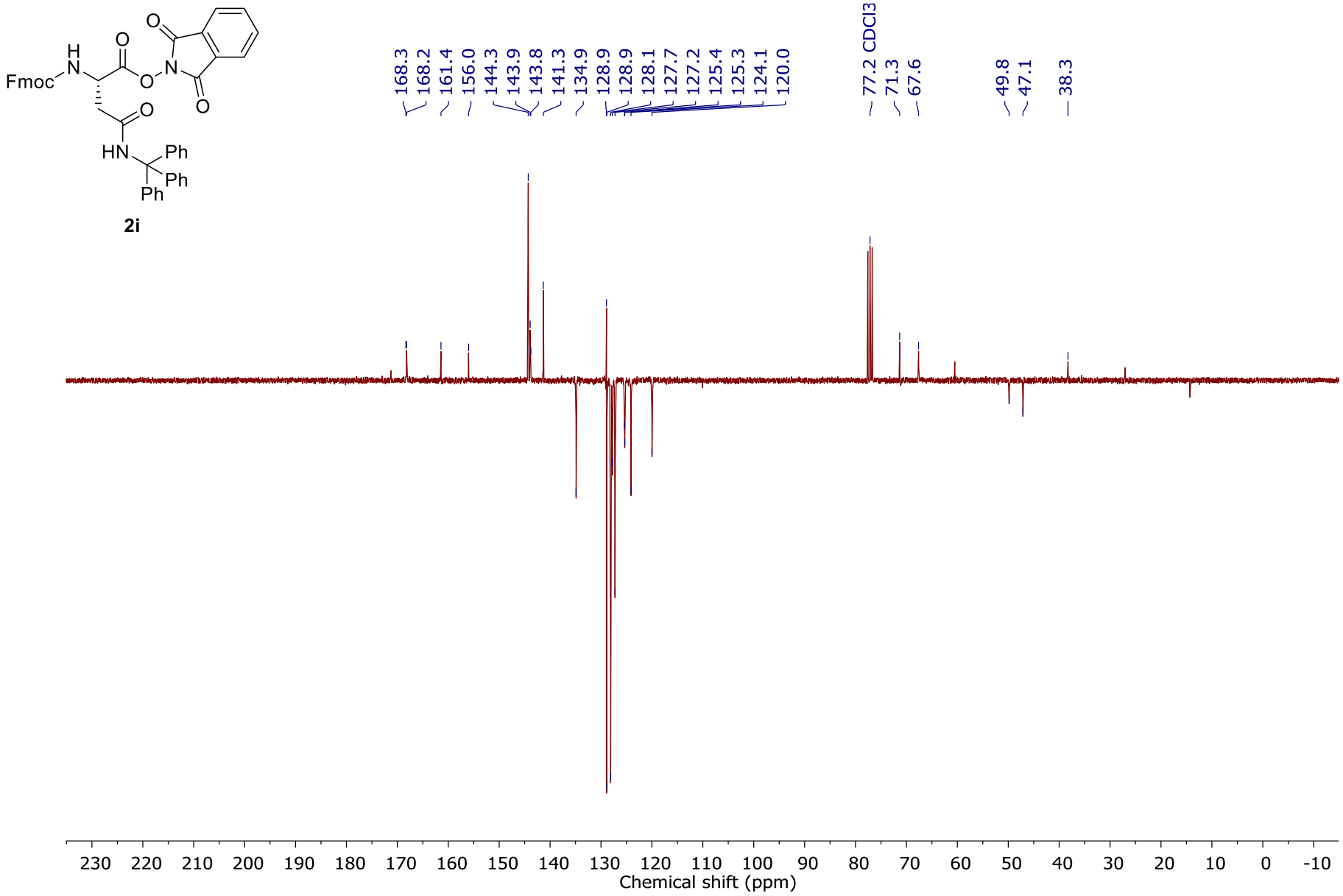

7.86
7.85
7.84
7.83
7.82
7.81
7.76
7.74
7.73
7.72
7.71
7.61
7.58
7.40
7.37
7.35
7.31
7.29
7.26
CDCl3
5.80
5.78
5.04
5.02
5.00
4.97
4.46
4.44
4.24
4.21
4.19
2.76
2.72
2.69
2.66
2.62
2.42
2.39
2.37
2.35
2.33
2.26
2.23
2.21
2.14
Fmoc
H
N
O
O
N
O
O
O
S
2g
2.12
4.20
2.00
2.20
2.01
1.06
0.83
1.95
0.85
2.07
1.90
3.24
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

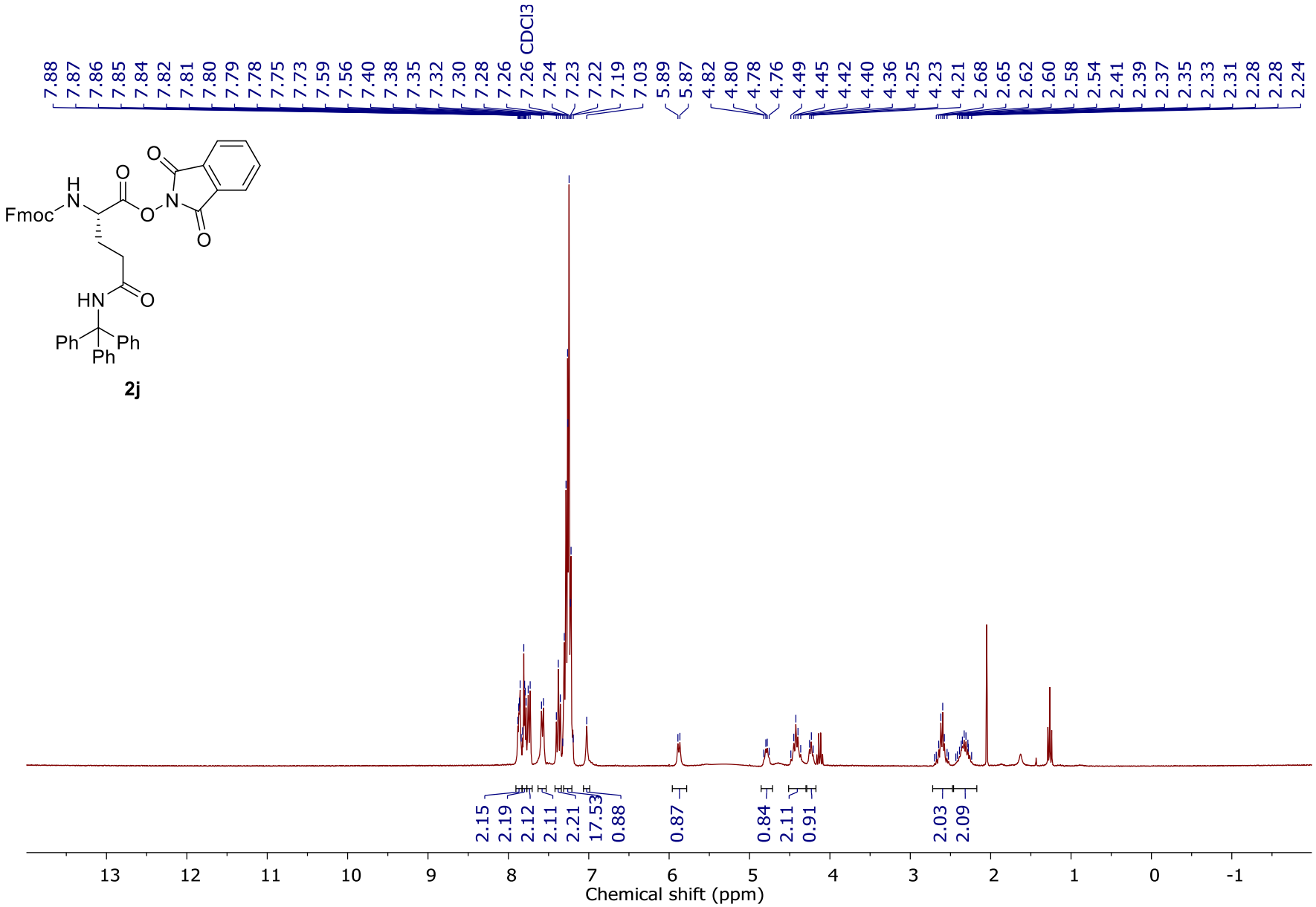

Fmoc
H
N
O
O
O
N
O
O
S
2g
168.9
161.4
155.6
143.8
143.5
141.2
134.9
128.7
127.7
127.1
125.0
124.0
119.9
77.2 CDCl3
67.2
51.7
47.1
31.9
29.5
15.4
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

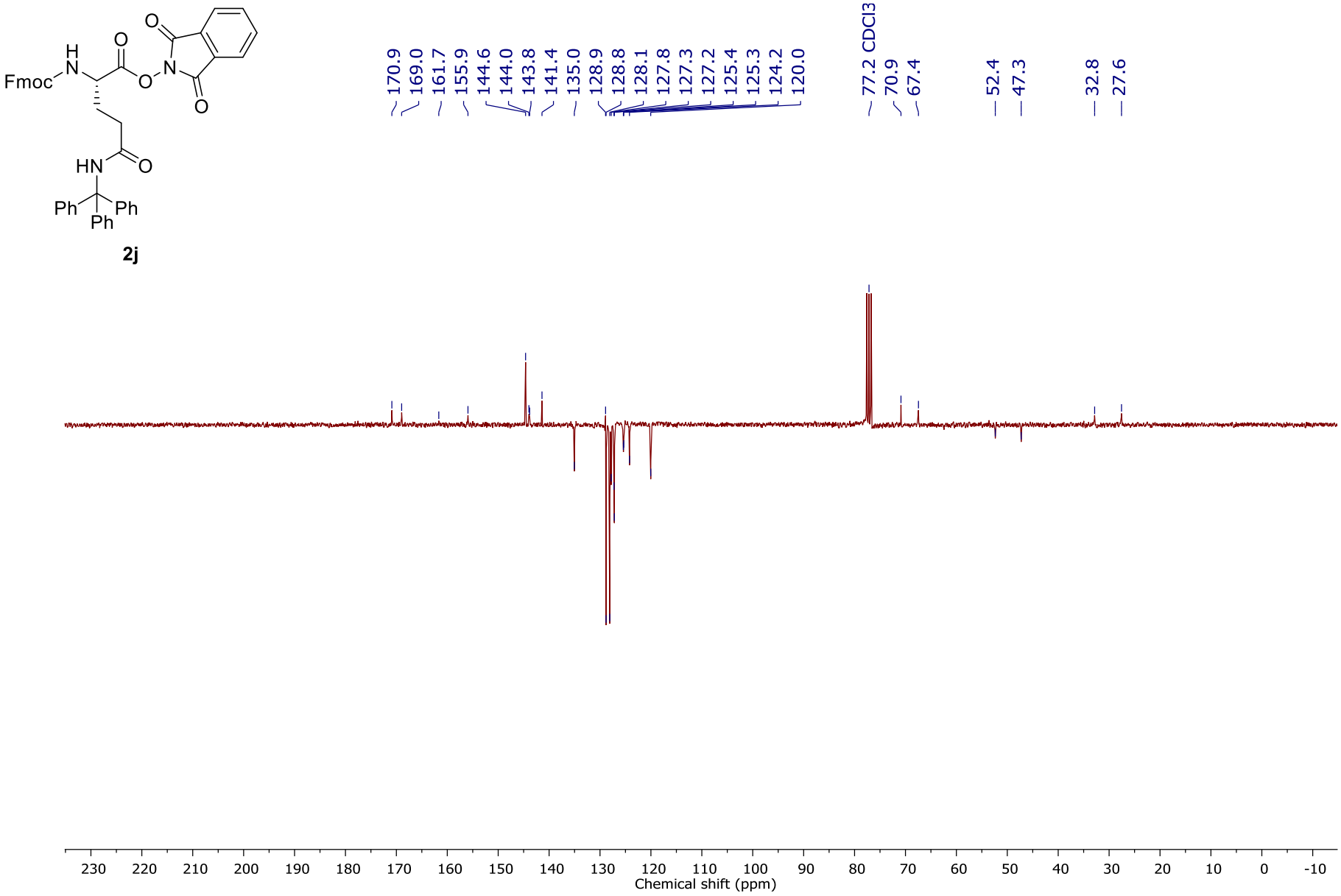

Fmoc
H
N
O
O
N
O
O
2h
7.92
7.89
7.88
7.83
7.81
7.78
7.75
7.58
7.55
7.53
7.43
7.40
7.38
7.35
7.33
7.31
7.29
7.26 CDCl3
5.24
5.21
5.17
5.13
5.11
4.51
4.49
4.47
4.45
4.41
4.39
4.35
4.24
4.21
4.19
3.42
3.37
3.32
3.29
2.00
4.16
2.00
2.27
6.72
1.62
1.94
0.88
1.74
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
O
O
O
N
O
2h
168.5
161.5
155.4
143.9
143.7
141.4
135.0
134.5
129.9
128.9
128.9
127.9
127.7
127.2
125.2
125.2
124.2
120.1
77.2 CDCl3
67.4
53.1
47.2
38.3
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
Chemical shift (ppm)

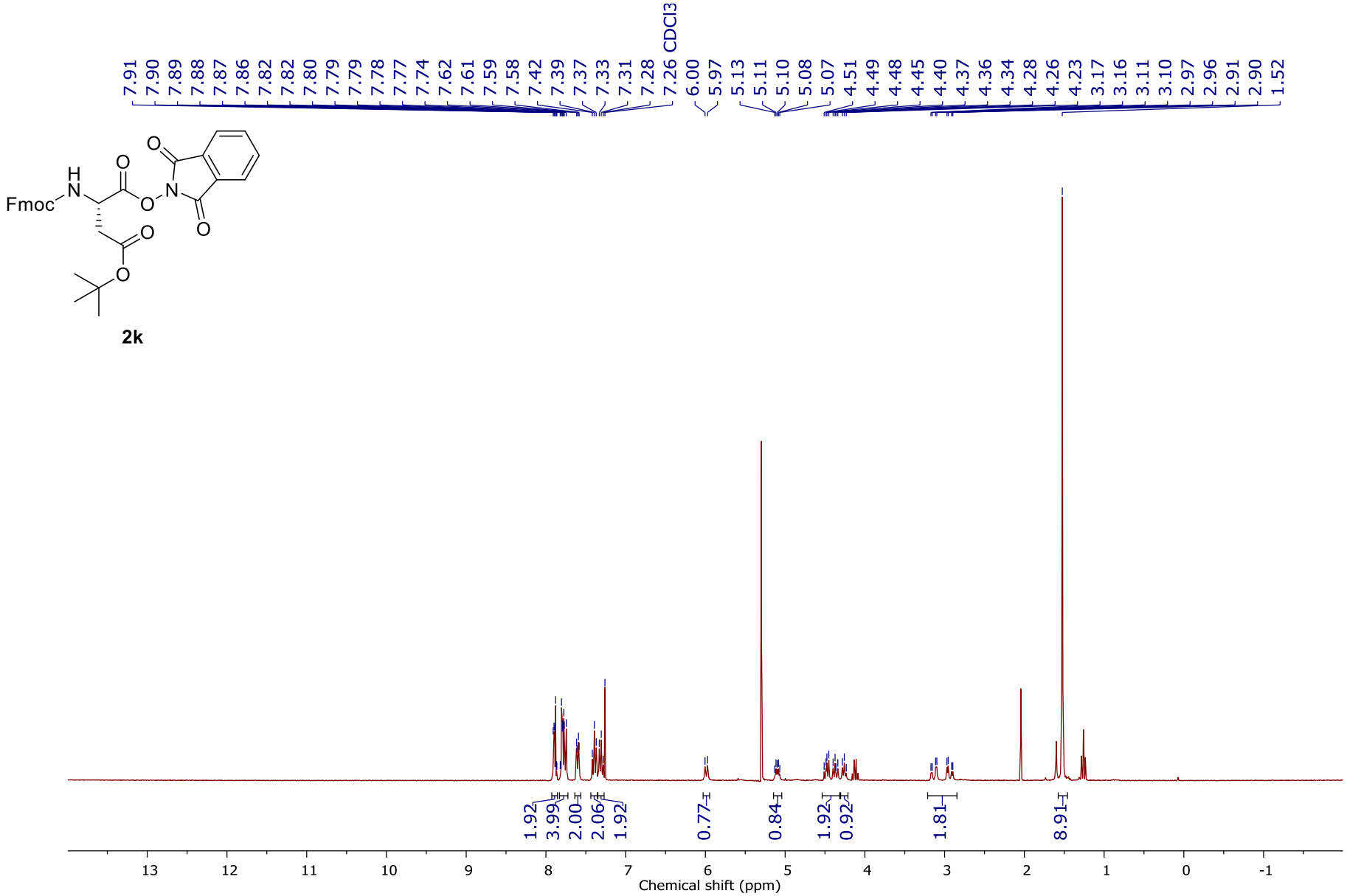

7.86
7.85
7.84
7.83
7.82
7.79
7.78
7.77
7.76
7.75
7.73
7.60
7.59
7.58
7.56
7.40
7.38
7.35
7.32
7.28
7.27
7.26 CDCl3
7.26
7.24
7.22
7.21
7.08
6.53
6.50
5.05
5.04
5.03
4.42
4.39
4.39
4.36
4.34
4.32
4.28
4.23
4.20
4.18
3.25
3.23
3.20
3.18
3.01
2.99
2.96
2.94
Fmoc
HN
O
O
O
N
O
O
O
HN
Ph
Ph
Ph
2i
1.92
3.69
2.00
1.85
16.92
0.88
0.75
0.79
1.71
0.89
1.61
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
O
O
N
O
O
O
HN
Ph
Ph
Ph
2i
168.3
168.2
161.4
156.0
144.3
143.9
143.8
141.3
134.9
128.9
128.9
128.1
127.7
127.2
125.4
125.3
124.1
120.0
77.2 CDCl3
71.3
67.6
49.8
47.1
38.3
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
Chemical shift (ppm)

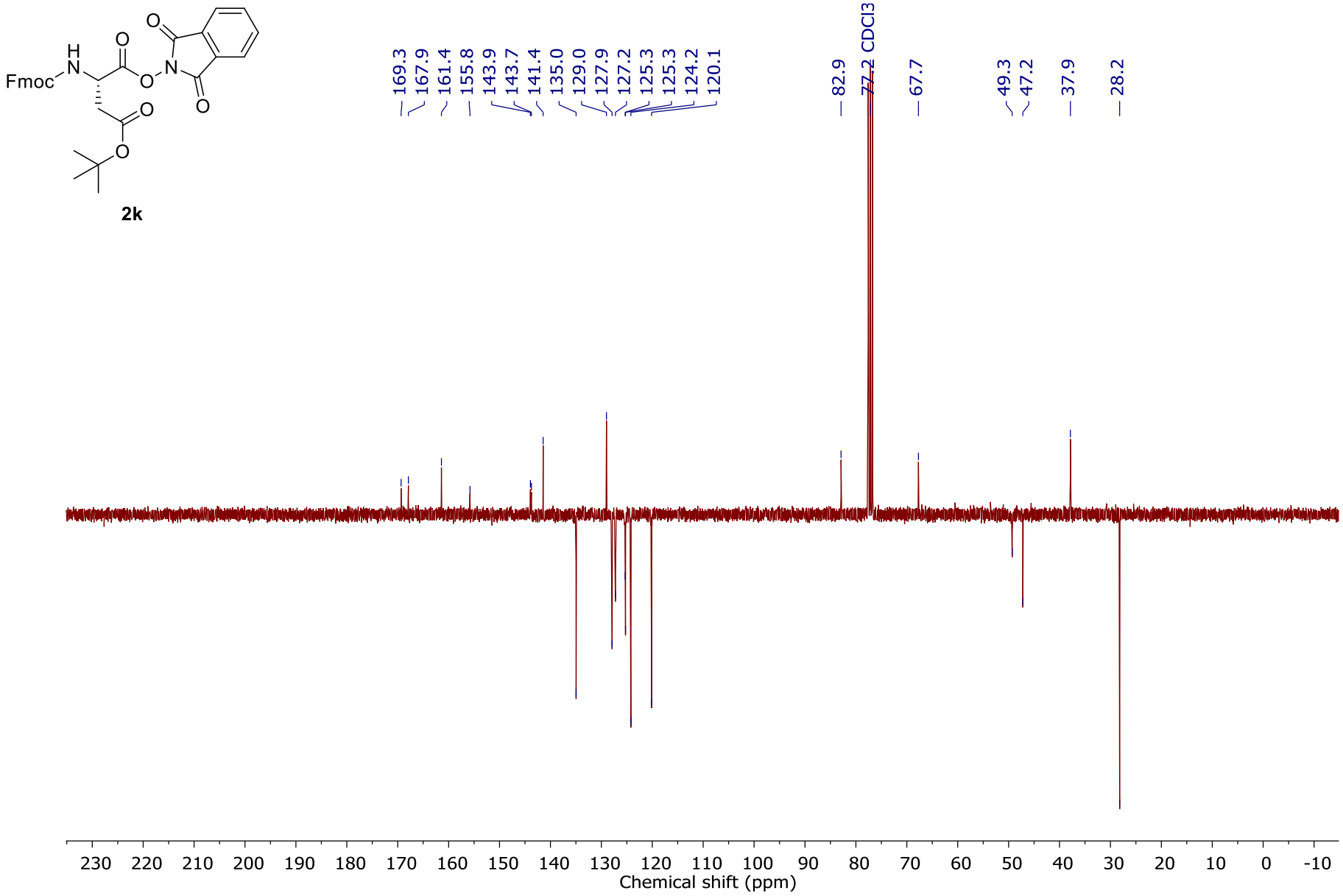

7.88 7.87 7.86 7.85 7.84 7.82 7.81 7.80 7.79 7.78 7.75 7.73 7.59 7.56 7.40 7.38 7.35 7.32 7.30 7.28 7.26 CDCl3 7.24 7.23 7.22 7.19 7.03 5.89 5.87 4.82 4.80 4.78 4.76 4.49 4.45 4.42 4.40 4.36 4.25 4.23 4.21 2.68 2.65 2.62 2.60 2.58 2.54 2.41 2.39 2.37 2.35 2.33 2.31 2.28 2.28 2.24
Fmoc
H
N
O
O
O
N
O
HN
O
Ph
Ph
Ph
2j
2.15 2.19 2.12 2.11 2.21 17.53 0.88 0.87 0.84 2.11 0.91 2.03 2.09
13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1
Chemical shift (ppm)

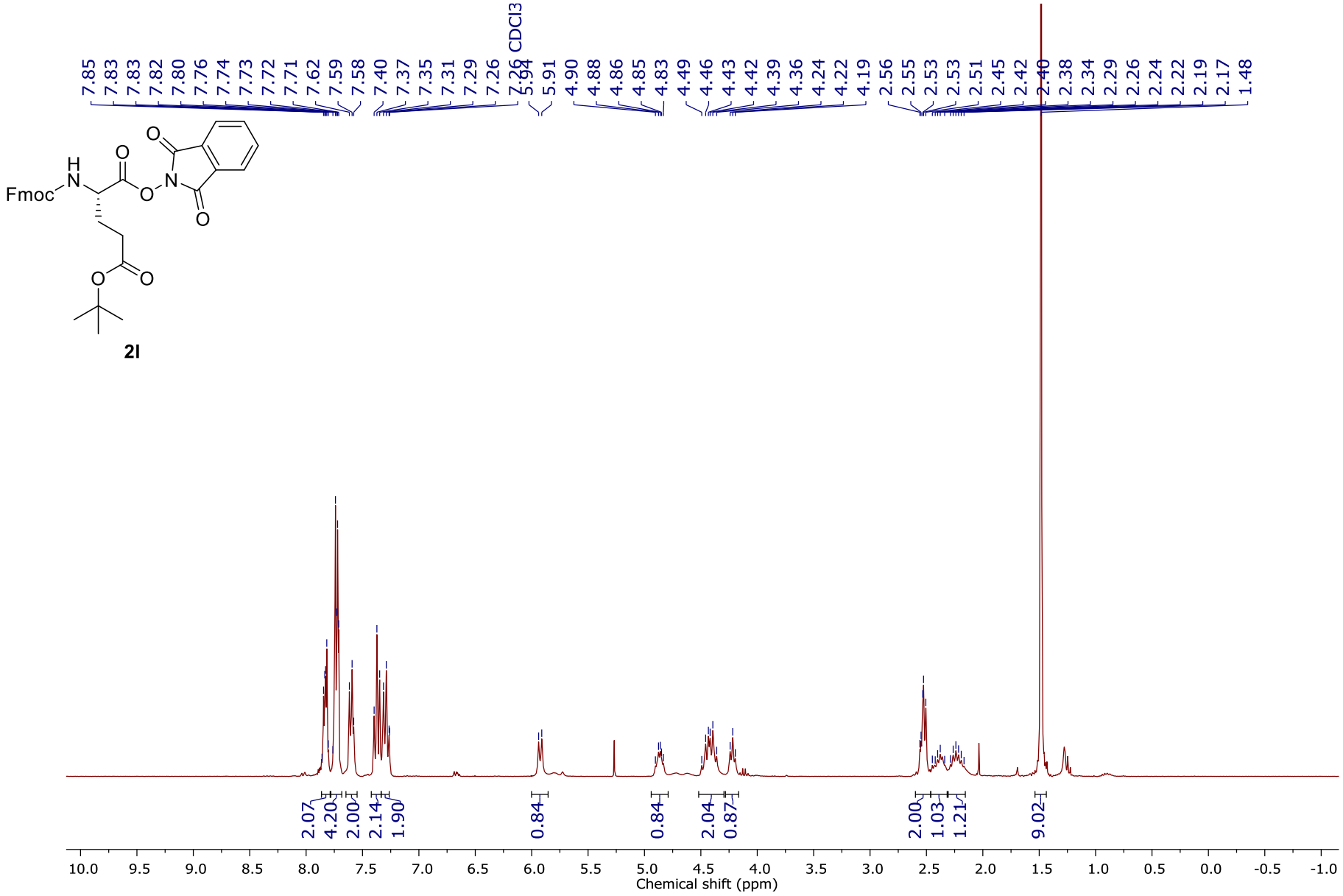

Fmoc
H
N
O
O
N
O
O
HN
O
Ph
Ph
Ph
170.9
169.0
161.7
155.9
144.6
144.0
143.8
141.4
135.0
128.9
128.8
128.1
127.8
127.3
127.2
125.4
125.3
124.2
120.0
77.2 CDCl3
70.9
67.4
52.4
47.3
32.8
27.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

2j

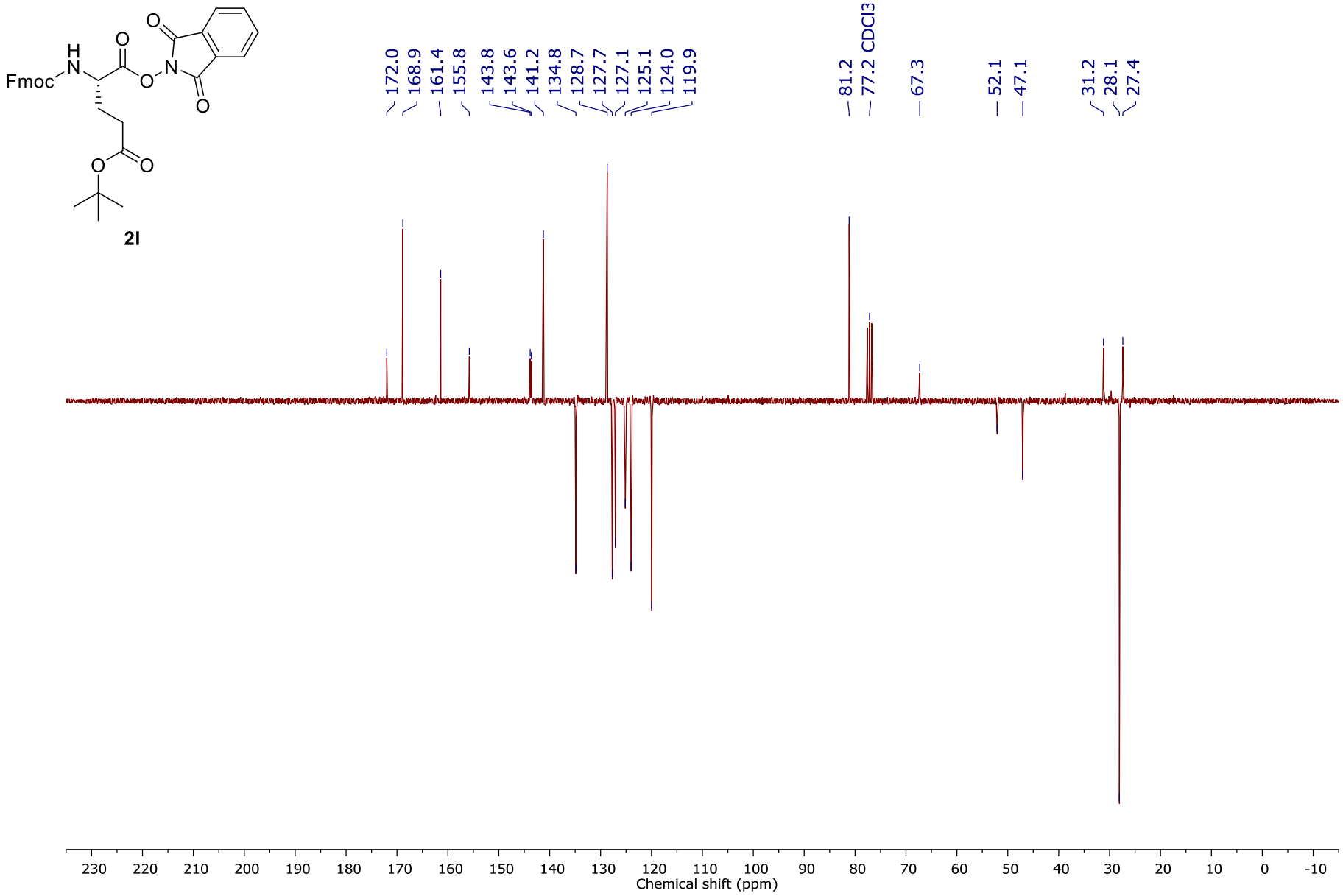

7.91
7.90
7.89
7.88
7.87
7.86
7.82
7.82
7.80
7.79
7.79
7.78
7.77
7.74
7.62
7.61
7.59
7.58
7.42
7.39
7.37
7.33
7.31
7.28
7.26 CDCl3
6.00
5.97
5.13
5.11
5.10
5.08
5.07
4.51
4.49
4.48
4.45
4.40
4.37
4.36
4.34
4.28
4.26
4.23
3.17
3.16
3.11
3.10
2.97
2.96
2.91
2.90
1.52
Fmoc
H
N
O
O
O
N
O
O
O
O
O
1.92
3.99
2.00
2.06
1.92
0.77
0.84
1.92
0.92
1.81
8.91
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

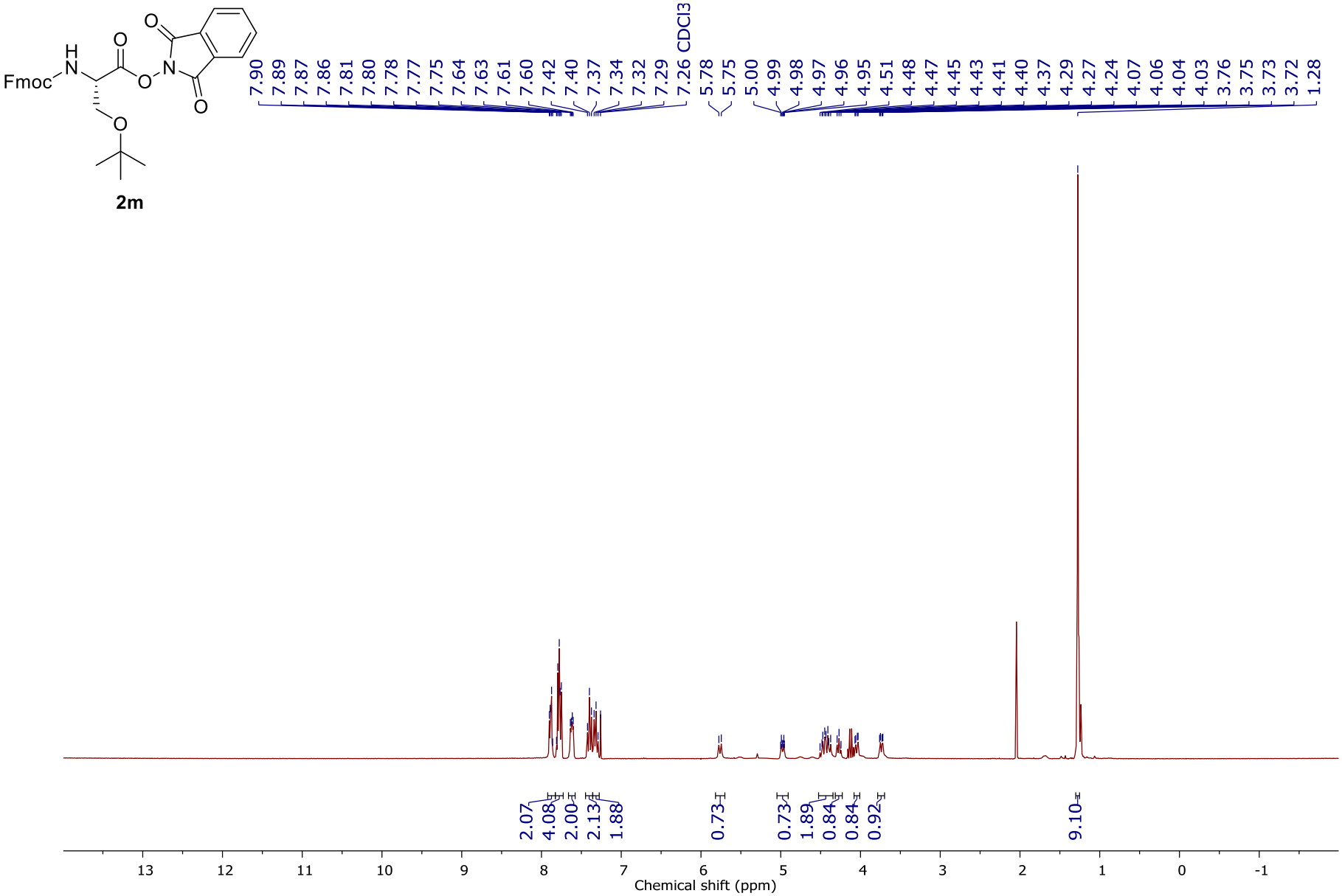
2k

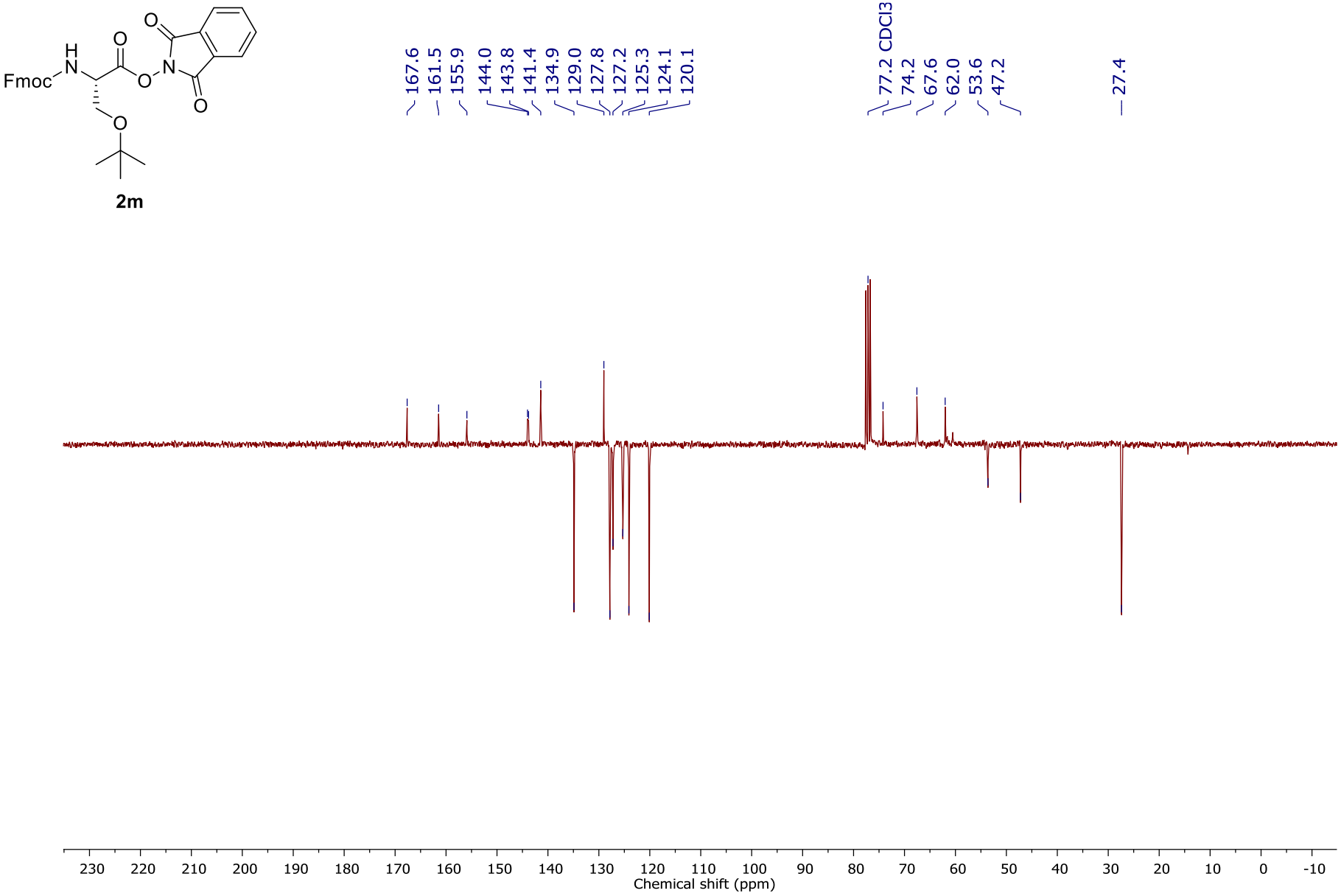

Fmoc
H
N
O
O
N
O
O
O
O
O
2k
169.3
167.9
161.4
155.8
143.9
143.7
141.4
135.0
129.0
127.9
127.2
125.3
125.3
124.2
120.1
82.9
77.2 CDCl3
67.7
49.3
47.2
37.9
28.2
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

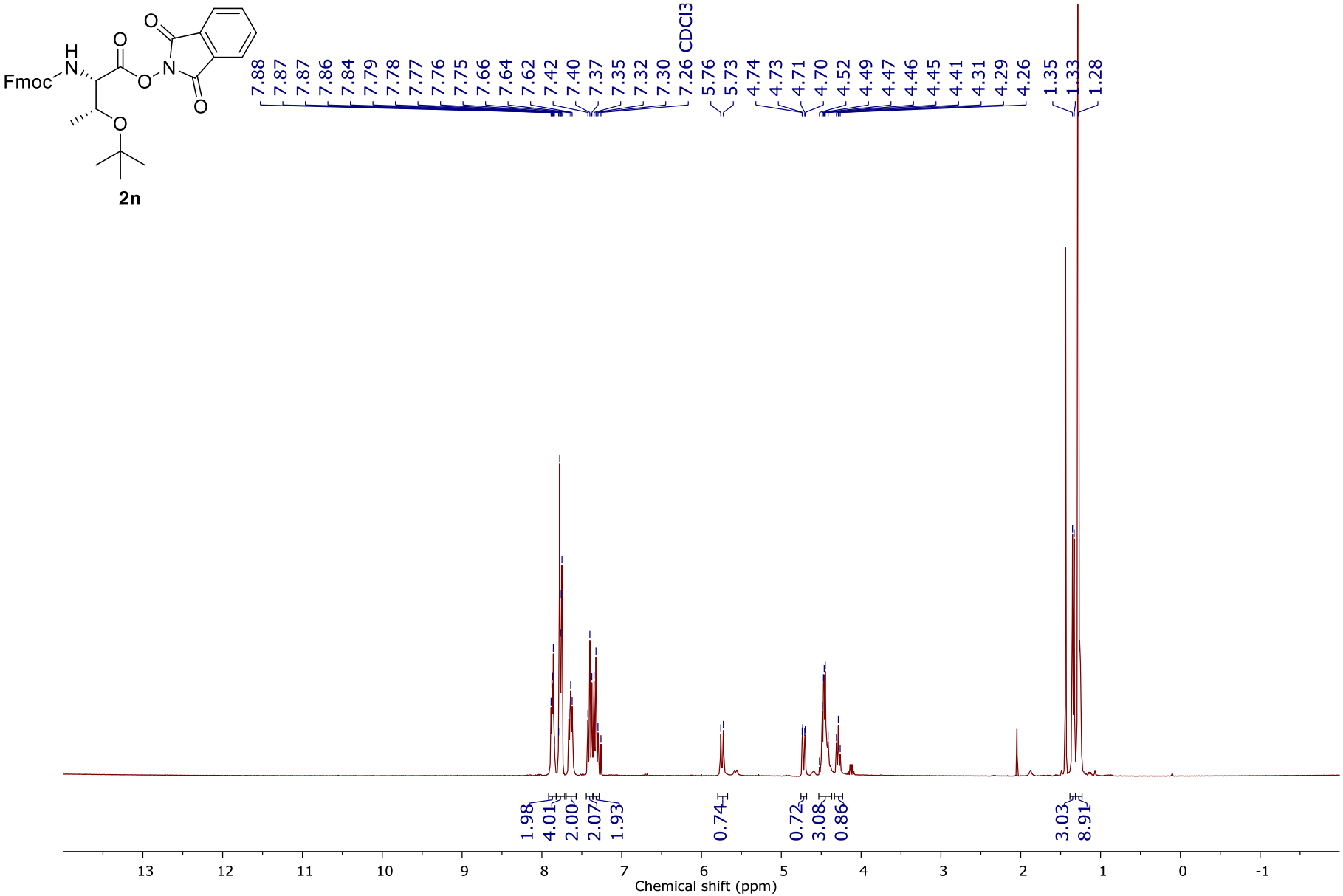

7.85
7.83
7.83
7.82
7.80
7.76
7.74
7.73
7.72
7.71
7.62
7.59
7.58
7.40
7.37
7.35
7.31
7.29
7.26
CDCl3
5.94
5.91
4.90
4.88
4.86
4.85
4.83
4.49
4.46
4.43
4.42
4.39
4.36
4.24
4.22
4.19
2.56
2.55
2.53
2.53
2.51
2.45
2.42
2.40
2.38
2.34
2.29
2.26
2.24
2.22
2.19
2.17
1.48
Fmoc
H
N
O
O
N
O
O
O
O
O
2.07
4.20
2.00
2.14
1.90
0.84
0.84
2.04
0.87
2.00
1.03
1.21
9.02
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Chemical shift (ppm)

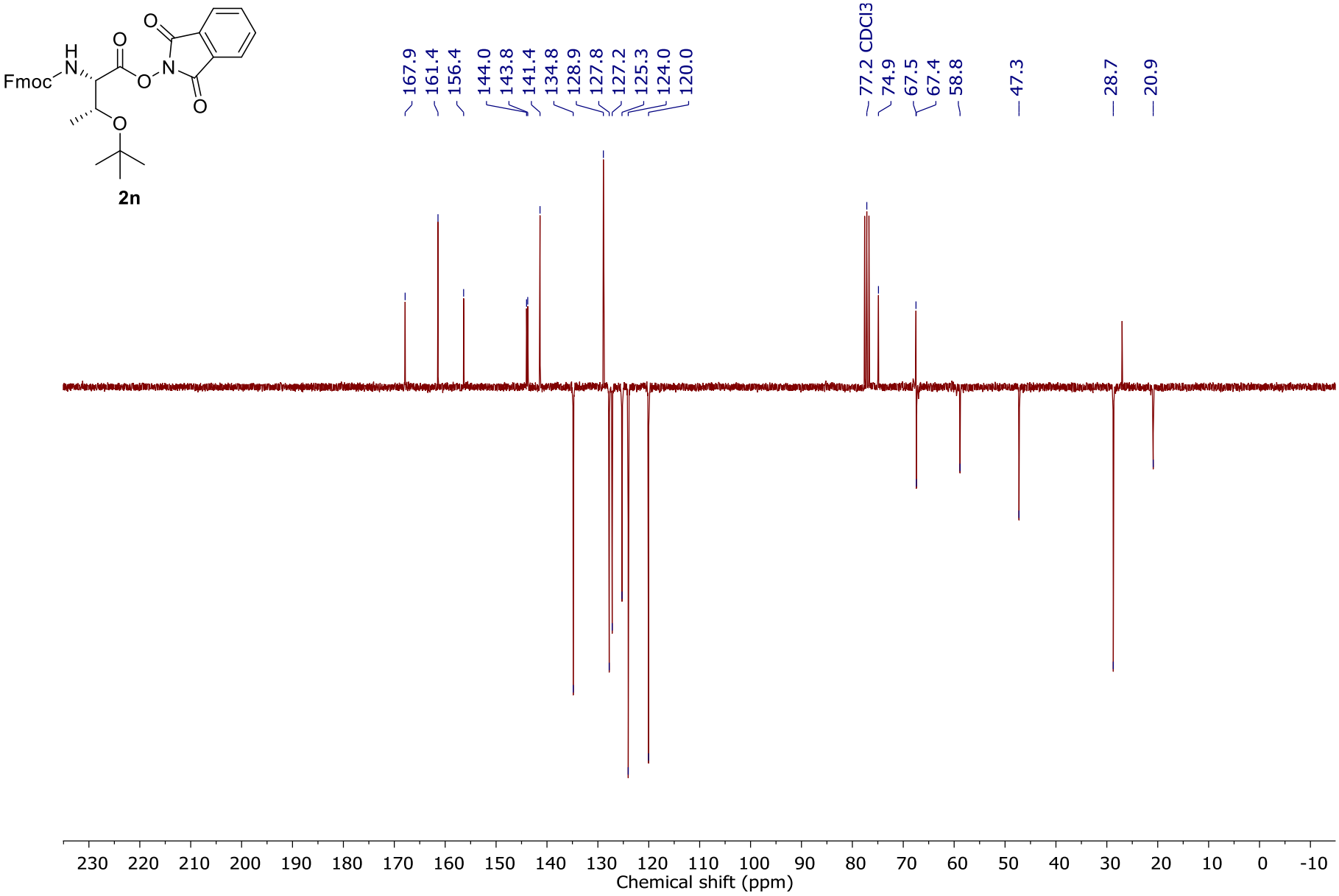
2l

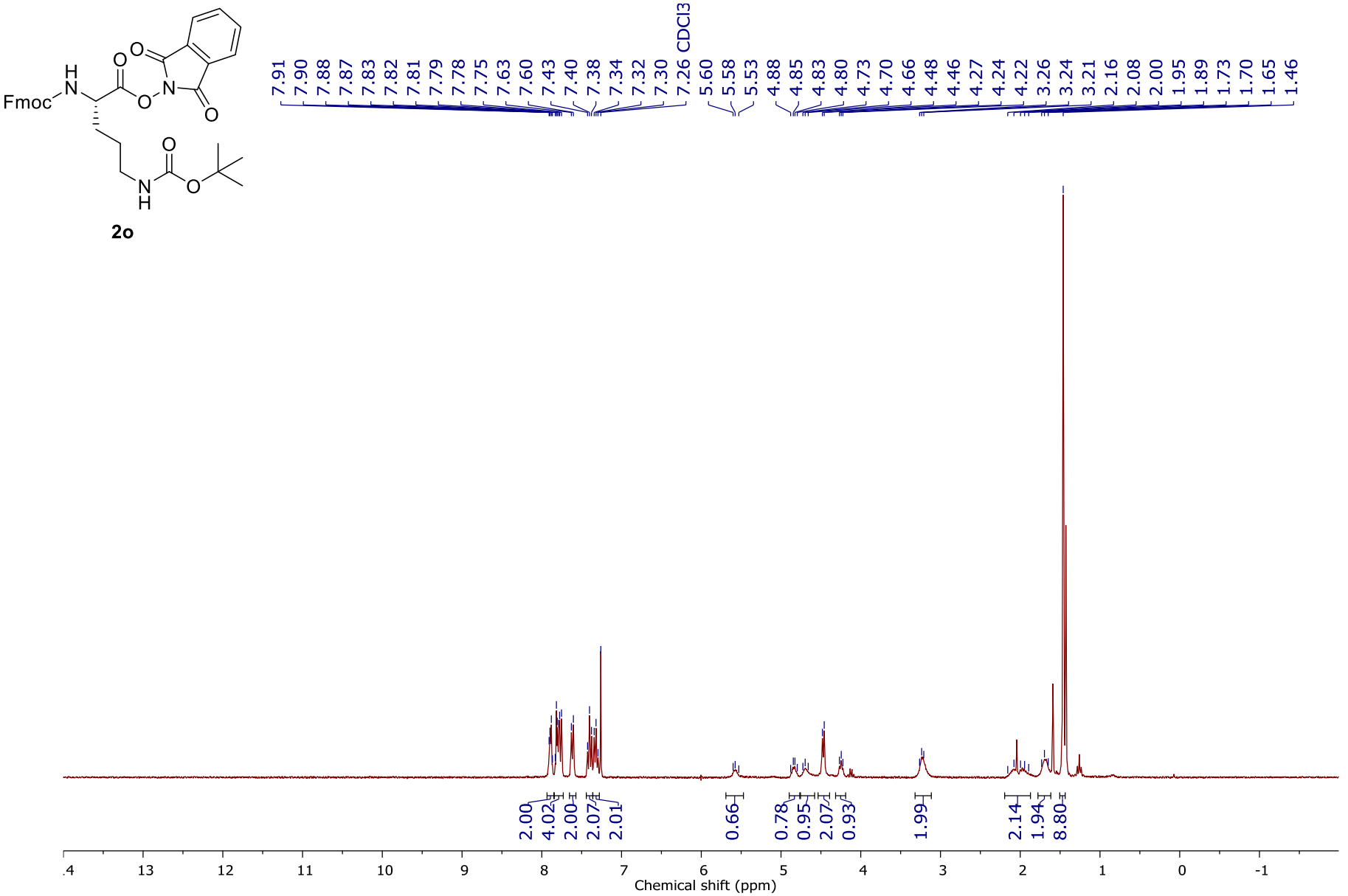

Fmoc
H
N
O
O
N
O
O
O
O
O
2l
172.0
168.9
161.4
155.8
143.8
143.6
141.2
134.8
128.7
127.7
127.1
125.1
124.0
119.9
81.2
77.2 CDCl3
67.3
52.1
47.1
31.2
28.1
27.4
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

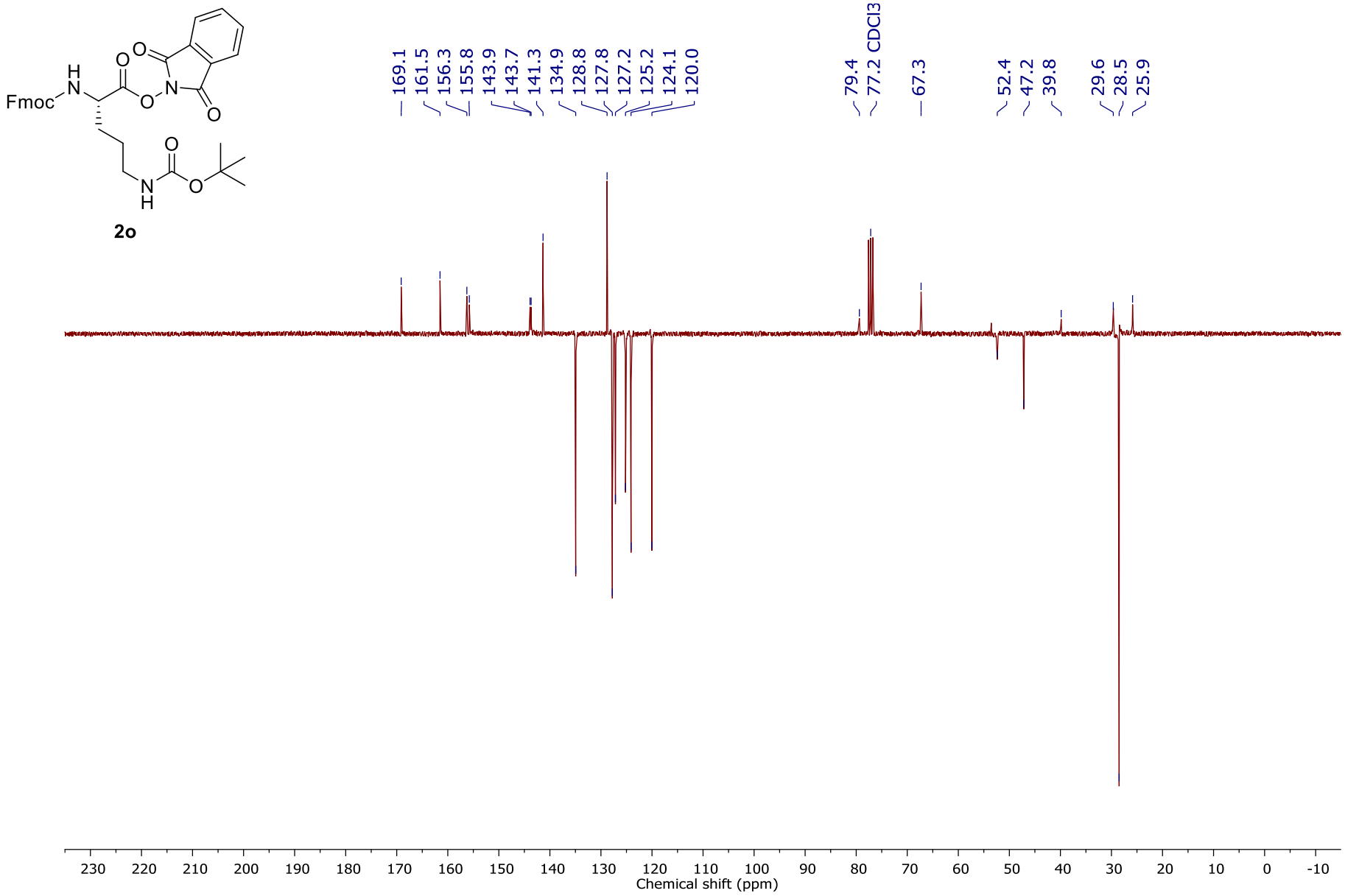

Fmoc
2m
7.90 7.89 7.87 7.86 7.81 7.80 7.78 7.77 7.75 7.64 7.63 7.61 7.60 7.42 7.40 7.37 7.34 7.32 7.29 7.26 CDCl3 5.78 5.75 5.00 4.99 4.98 4.97 4.96 4.95 4.51 4.48 4.47 4.45 4.43 4.41 4.40 4.37 4.29 4.27 4.24 4.07 4.06 4.04 4.03 3.76 3.75 3.73 3.72 1.28
2.07 4.08 2.00 2.13 1.88 0.73 0.73 1.89 0.84 0.84 0.92 9.10
13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1
Chemical shift (ppm)

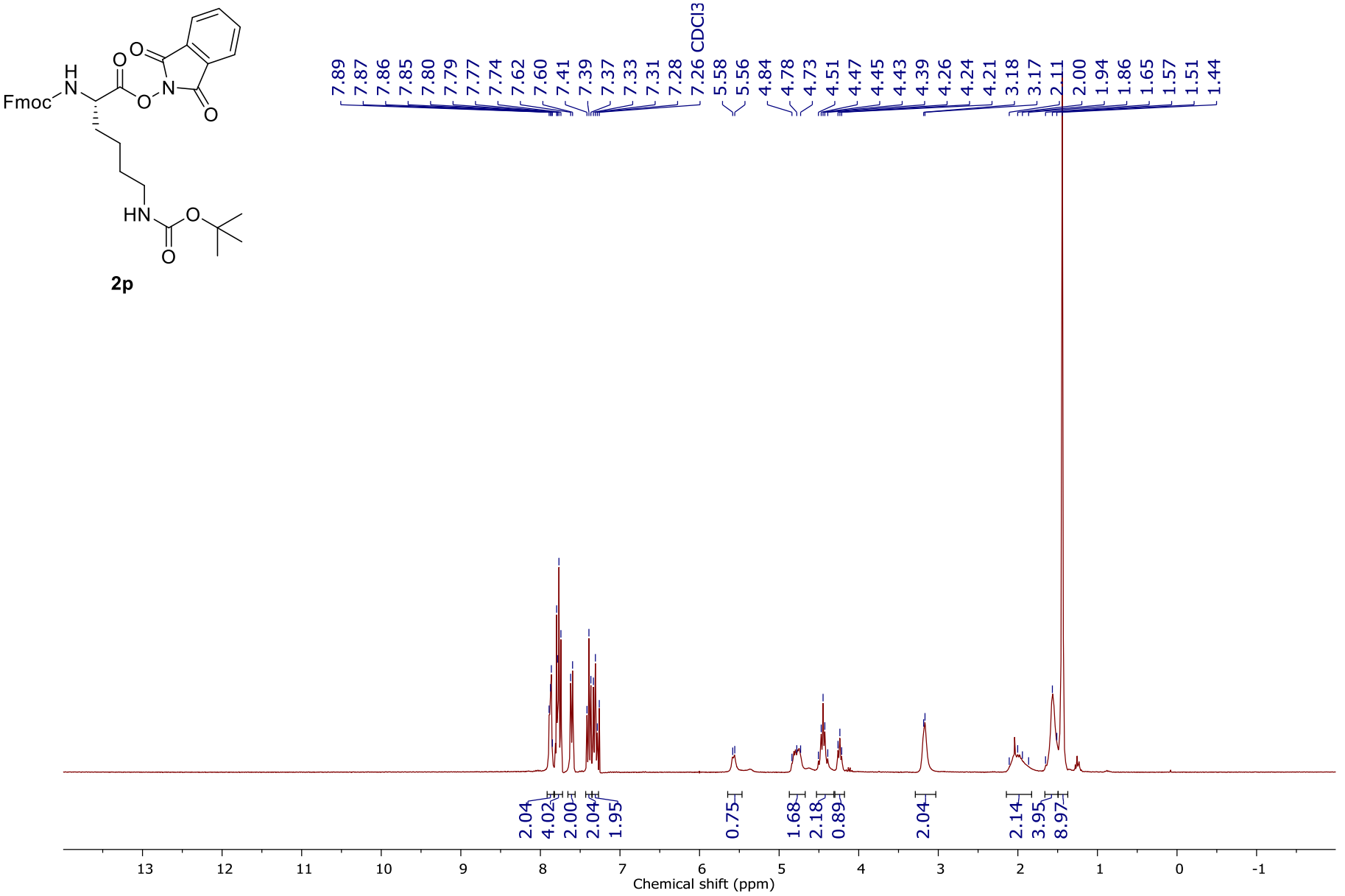

Fmoc
H
N
O
O
N
O
O
O
O
2m
167.6
161.5
155.9
144.0
143.8
141.4
134.9
129.0
127.8
127.2
125.3
124.1
120.1
77.2 CDCl3
74.2
67.6
62.0
53.6
47.2
27.4
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

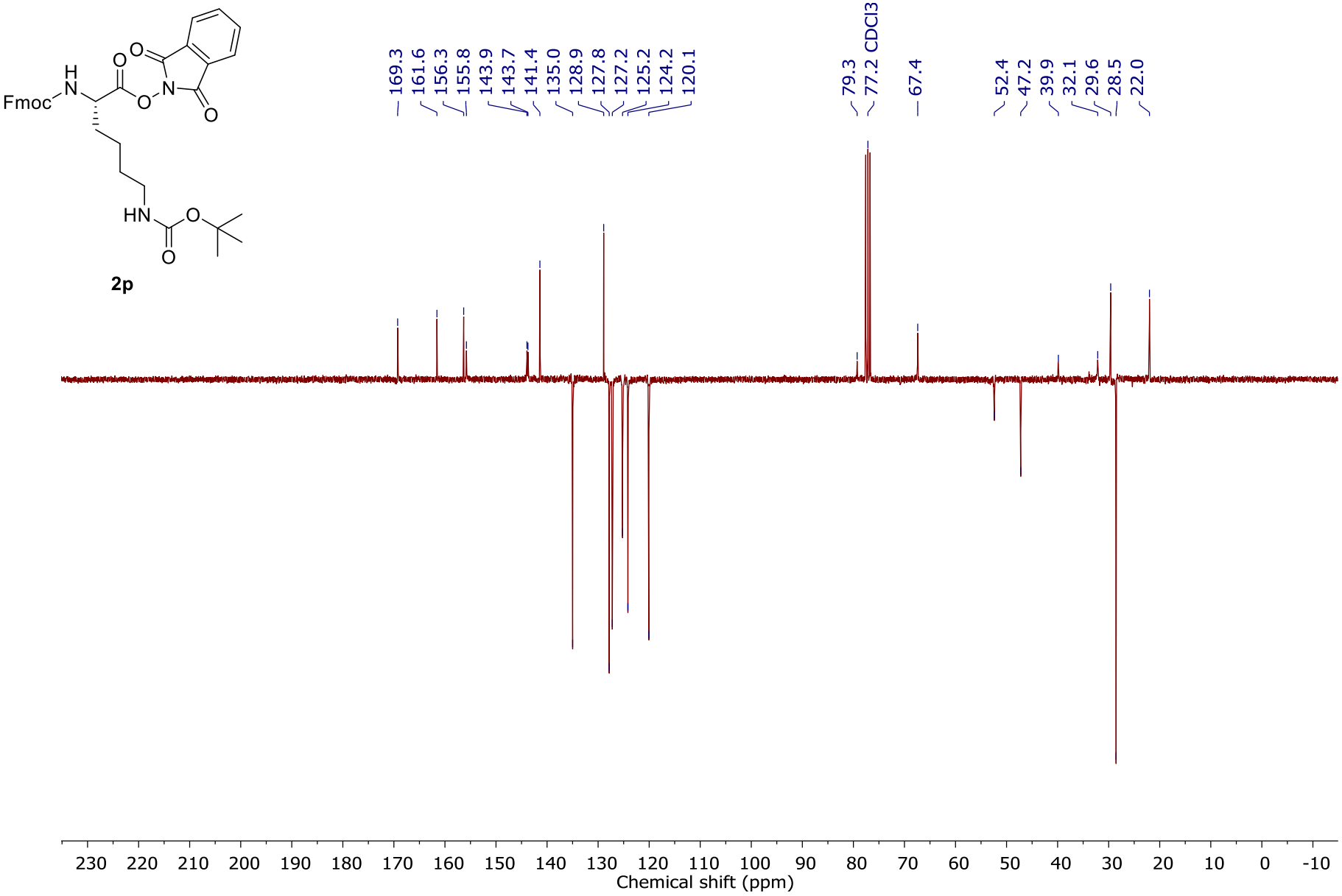

Fmoc
H
N
O
O
N
O
O
O
2n
7.88
7.87
7.87
7.86
7.84
7.79
7.78
7.77
7.76
7.75
7.66
7.64
7.62
7.42
7.40
7.37
7.35
7.32
7.30
7.26 CDCl3
5.76
5.73
4.74
4.73
4.71
4.70
4.52
4.49
4.47
4.46
4.45
4.41
4.31
4.29
4.26
1.35
1.33
1.28
1.98
4.01
2.00
2.07
1.93
0.74
0.72
3.08
0.86
3.03
8.91
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

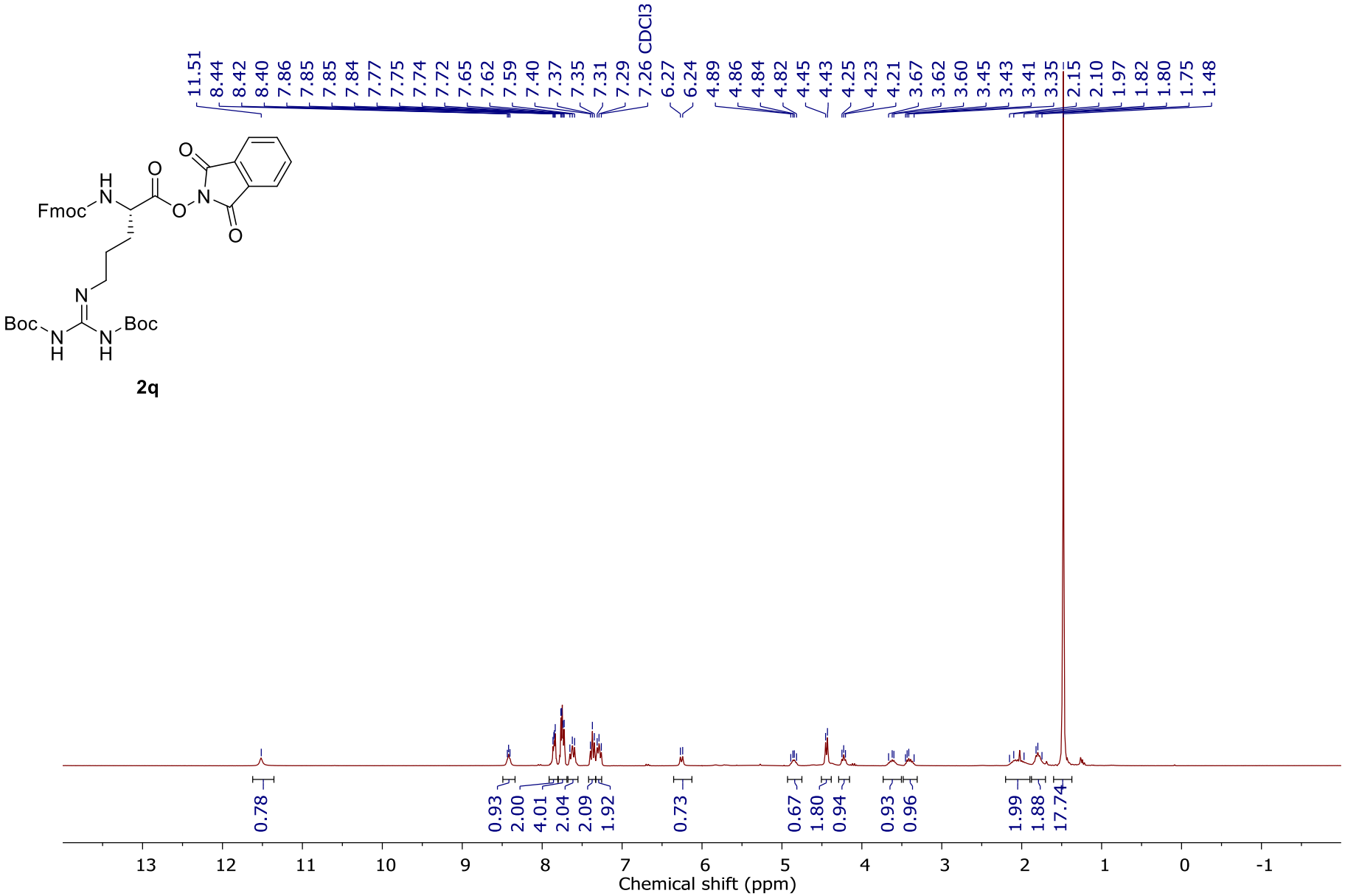

Fmoc
H
N
O
O
N
O
O
O
O
2n
167.9
161.4
156.4
144.0
143.8
141.4
134.8
128.9
127.8
127.2
125.3
124.0
120.0
77.2 CDCl3
74.9
67.5
67.4
58.8
47.3
28.7
20.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

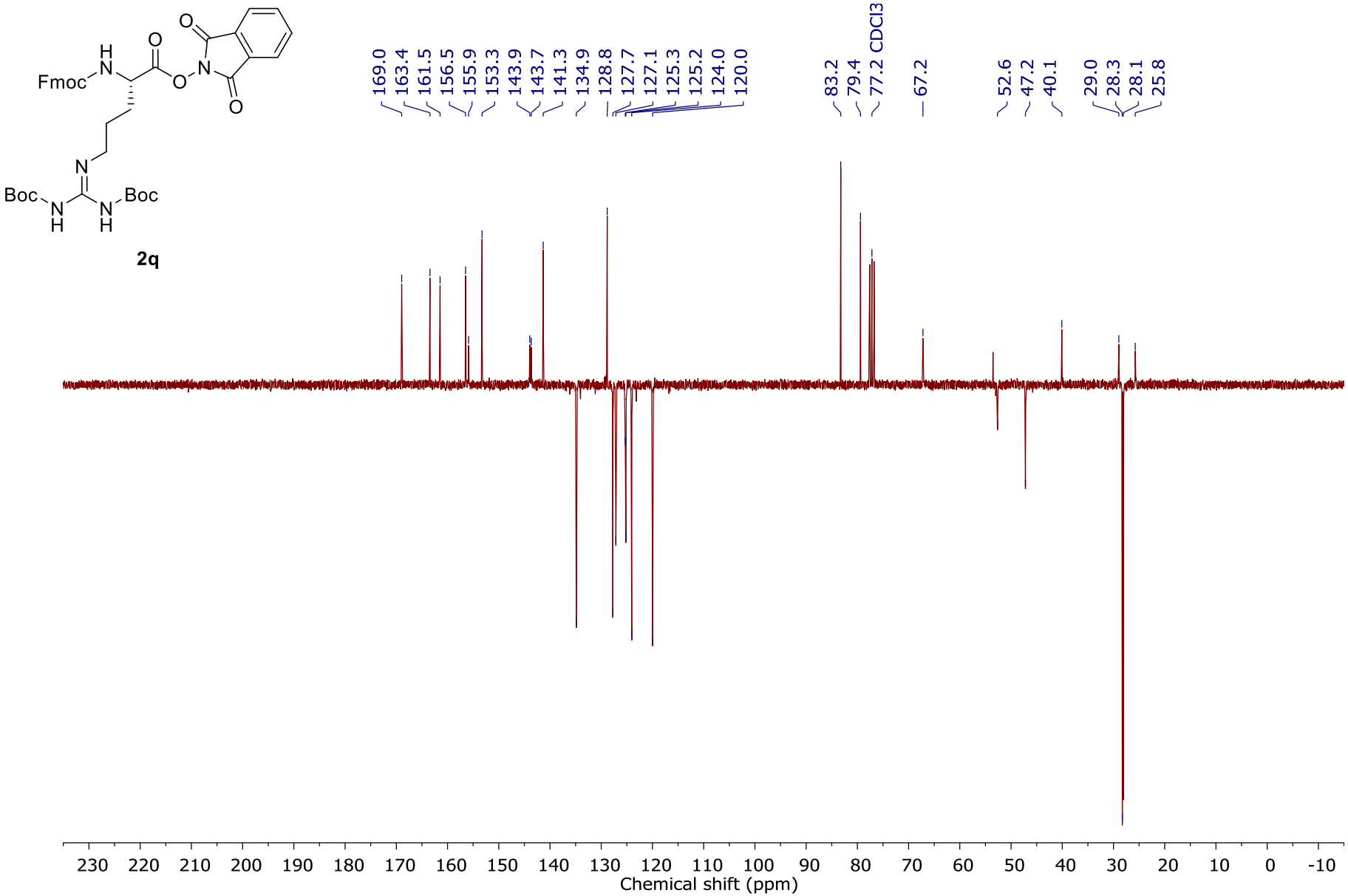

Fmoc
H
N
O
O
N
O
O
O
N
H
O
O
2o
7.91
7.90
7.88
7.87
7.83
7.82
7.81
7.79
7.78
7.75
7.63
7.60
7.43
7.40
7.38
7.34
7.32
7.30
7.26 CDCl3
5.60
5.58
5.53
4.88
4.85
4.83
4.80
4.73
4.70
4.66
4.48
4.46
4.27
4.24
4.22
3.26
3.24
3.21
2.16
2.08
2.00
1.95
1.89
1.73
1.70
1.65
1.46
2.00
4.02
2.00
2.07
2.01
0.66
0.78
0.95
2.07
0.93
1.99
2.14
1.94
8.80
Chemical shift (ppm)

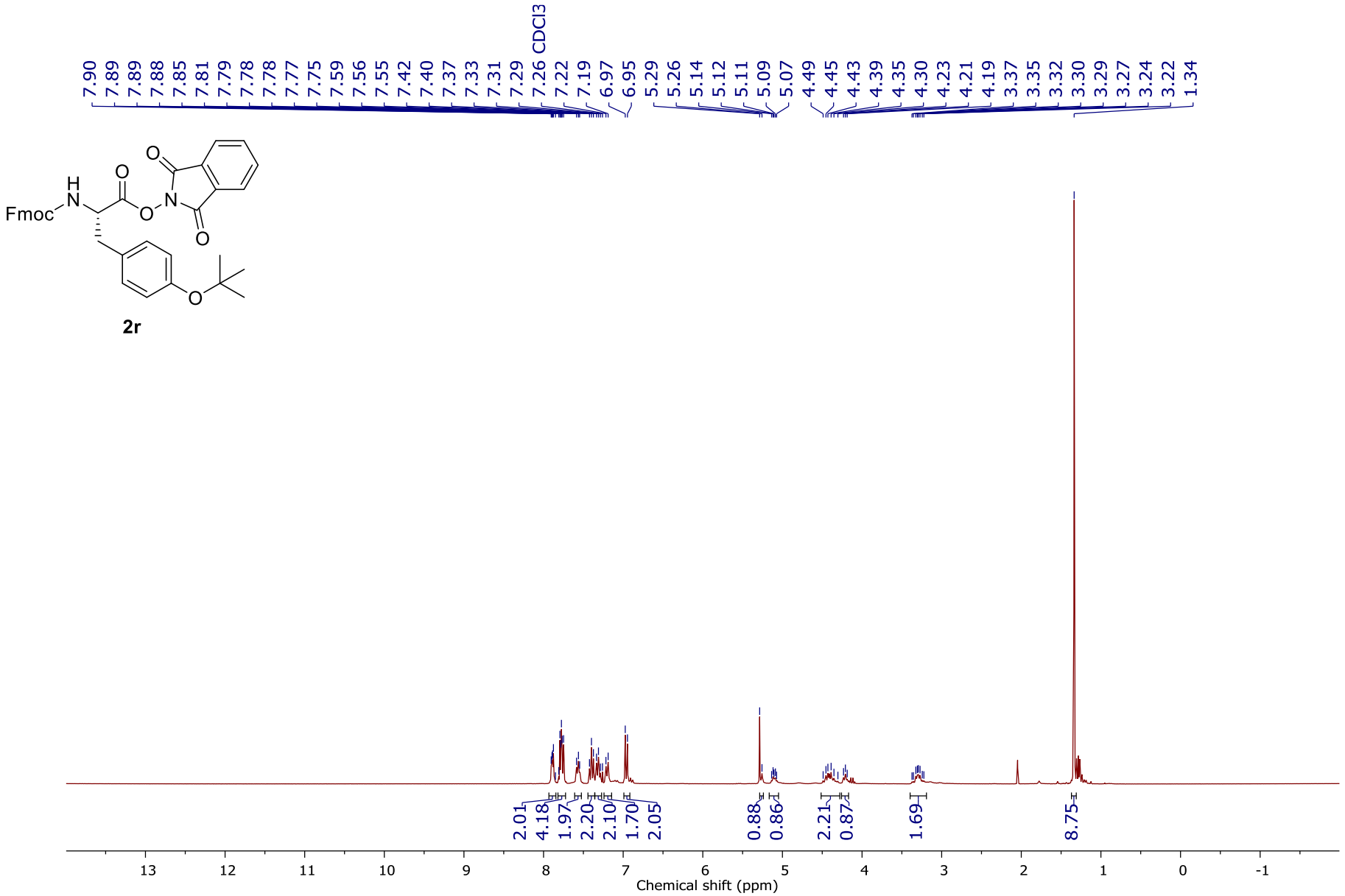

Fmoc
2o
169.1
161.5
156.3
155.8
143.9
143.7
141.3
134.9
128.8
127.8
127.2
125.2
124.1
120.0
79.4
77.2 CDCl3
67.3
52.4
47.2
39.8
29.6
28.5
25.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

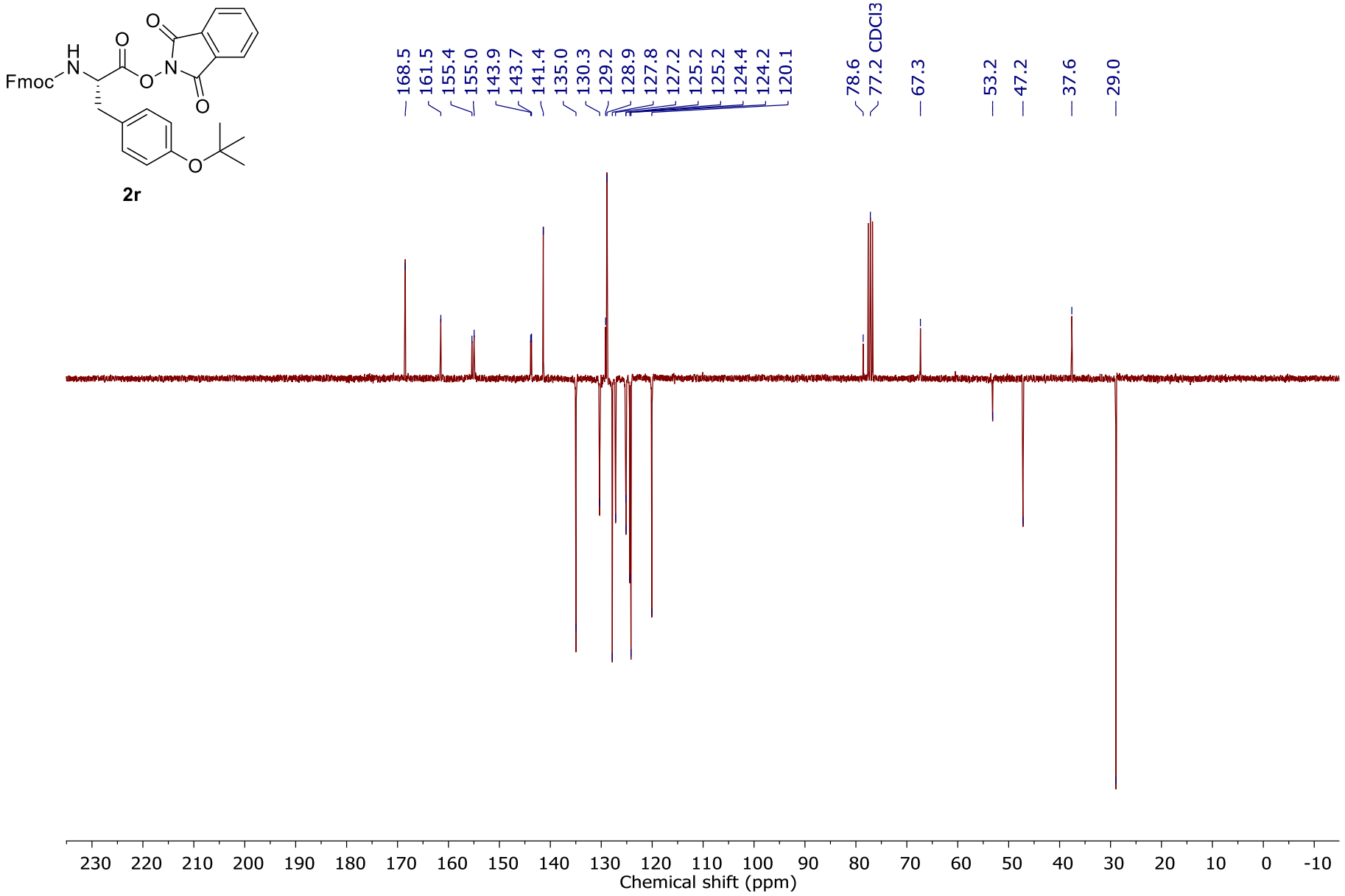

Fmoc
H
N
O
O
N
O
O
HN
O
O
2p
7.89
7.87
7.86
7.85
7.80
7.79
7.77
7.74
7.62
7.60
7.41
7.39
7.37
7.33
7.31
7.28
7.26 CDCl3
5.58
5.56
4.84
4.78
4.73
4.51
4.47
4.45
4.43
4.39
4.26
4.24
4.21
3.18
3.17
2.11
2.00
1.94
1.86
1.65
1.57
1.51
1.44
2.04
4.02
2.00
2.04
1.95
0.75
1.68
2.18
0.89
2.04
2.14
3.95
8.97
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

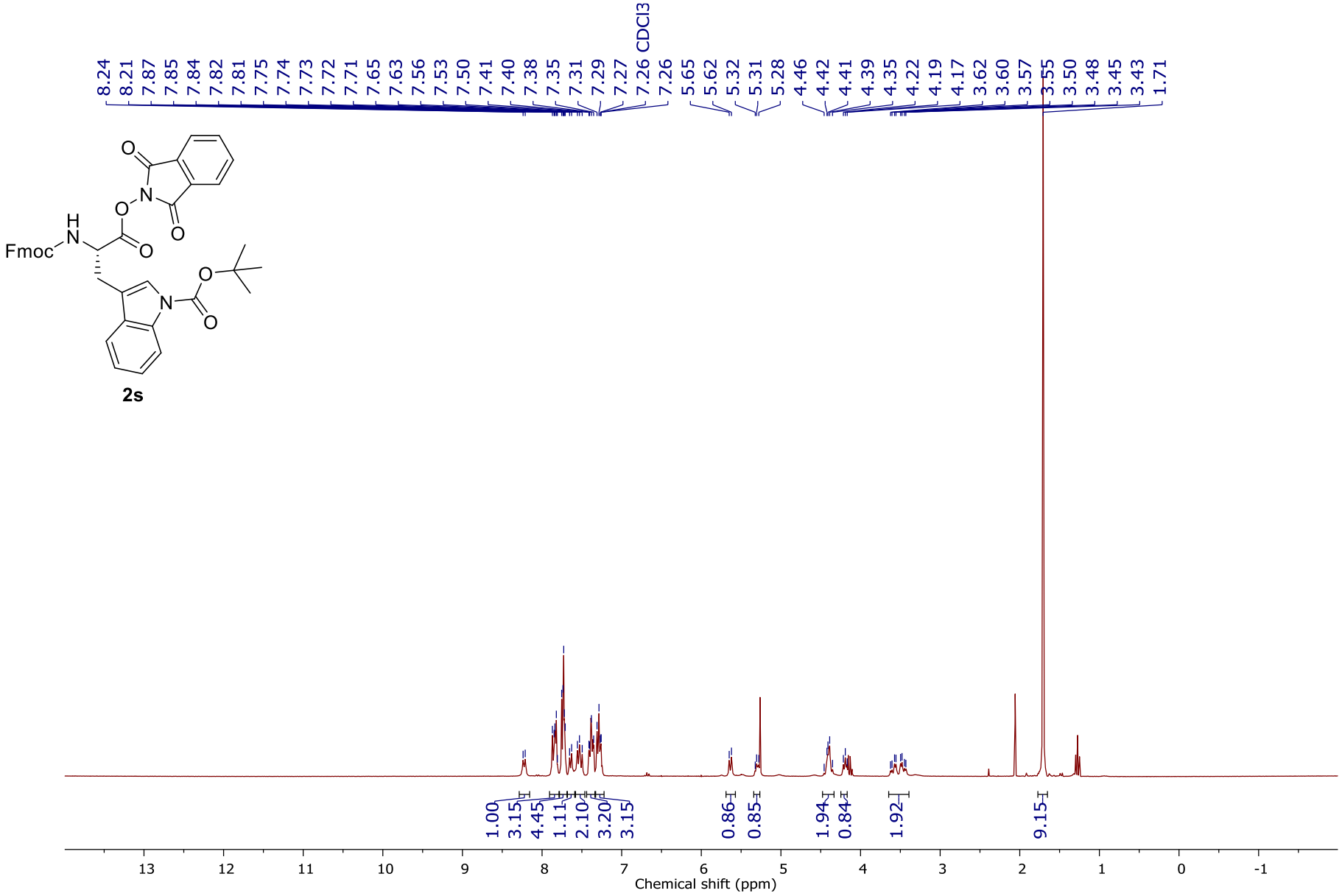

Fmoc
H
N
O
O
N
O
O
HN
O
O
2p
169.3
161.6
156.3
155.8
143.9
143.7
141.4
135.0
128.9
127.8
127.2
125.2
124.2
120.1
79.3
77.2 CDCl3
67.4
52.4
47.2
39.9
32.1
29.6
28.5
22.0
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

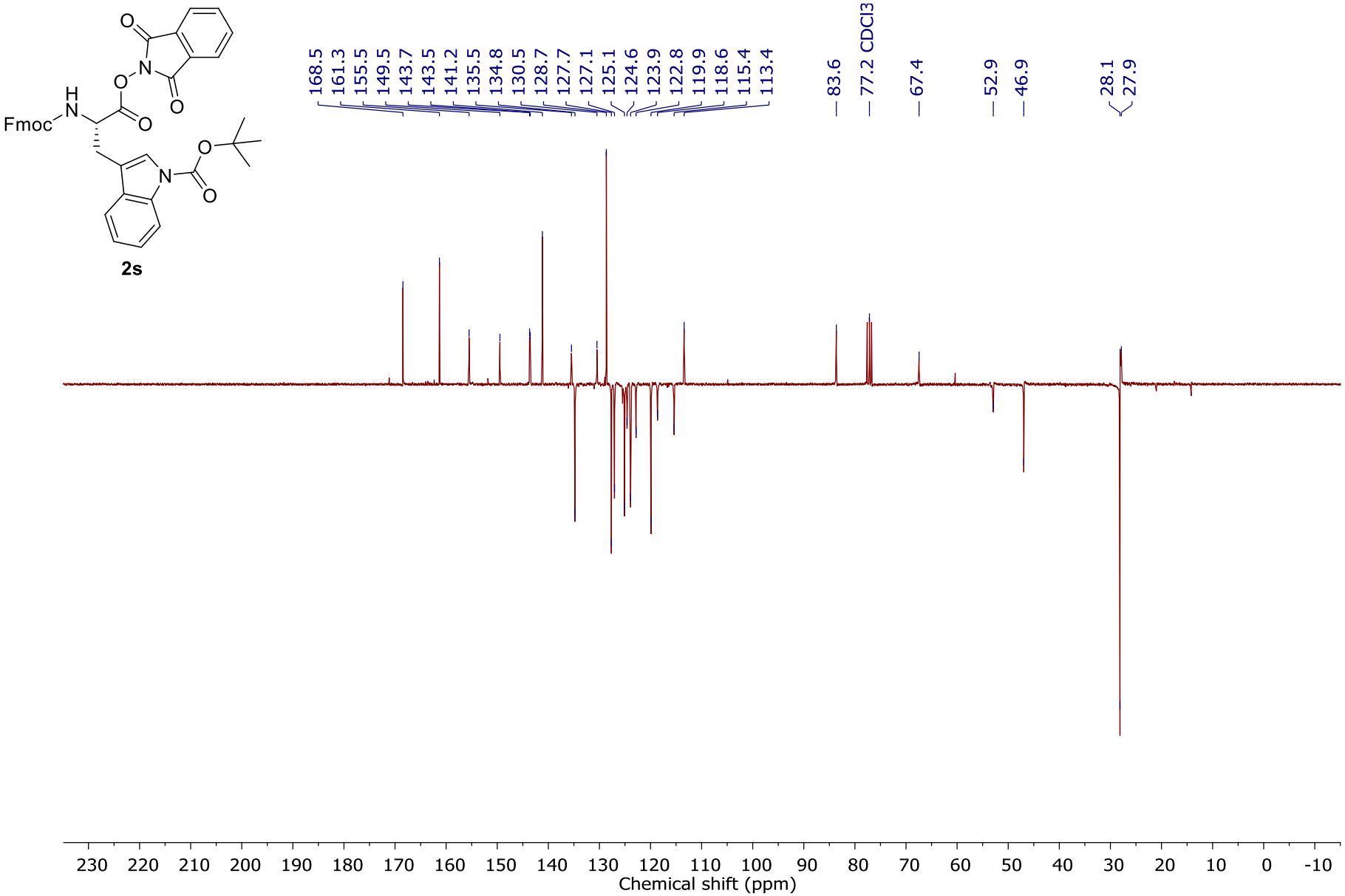

11.51
8.44
8.42
8.40
7.86
7.85
7.85
7.84
7.77
7.75
7.74
7.72
7.65
7.62
7.59
7.40
7.37
7.35
7.31
7.29
7.26 CDCl3
6.27
6.24
4.89
4.86
4.84
4.82
4.45
4.43
4.25
4.23
4.21
3.67
3.62
3.60
3.45
3.43
3.41
3.35
2.15
2.10
1.97
1.82
1.80
1.75
1.48
Fmoc
Boc
Boc
2q
0.78
0.93
2.00
4.01
2.04
2.09
1.92
0.73
0.67
1.80
0.94
0.93
0.96
1.99
1.88
17.74
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

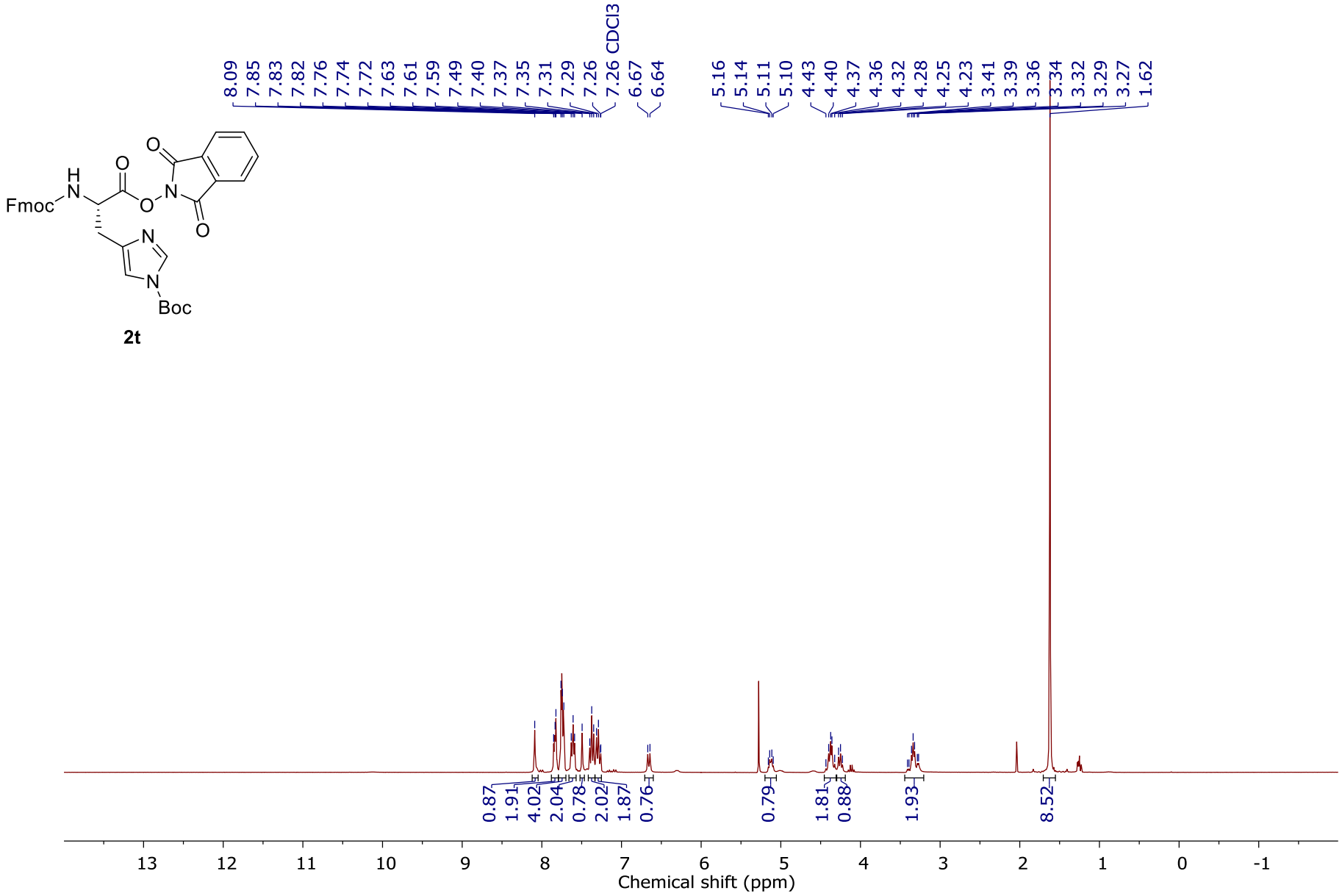

Fmoc
Boc
Boc
2q
169.0
163.4
161.5
156.5
155.9
153.3
143.9
143.7
141.3
134.9
128.8
127.7
127.1
125.3
125.2
124.0
120.0
83.2
79.4
77.2 CDCl3
67.2
52.6
47.2
40.1
29.0
28.3
28.1
25.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


7.90
7.89
7.89
7.88
7.85
7.81
7.79
7.78
7.78
7.77
7.75
7.59
7.56
7.55
7.42
7.40
7.37
7.33
7.31
7.29
7.26 CDCl3
7.22
7.19
6.97
6.95
5.29
5.26
5.14
5.12
5.11
5.09
5.07
4.49
4.45
4.43
4.39
4.35
4.30
4.23
4.21
4.19
3.37
3.35
3.32
3.30
3.29
3.27
3.24
3.22
1.34
Fmoc
H
N
O
O
N
O
O
O
2r
2.01
4.18
1.97
2.20
2.10
1.70
2.05
0.88
0.86
2.21
0.87
1.69
8.75
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

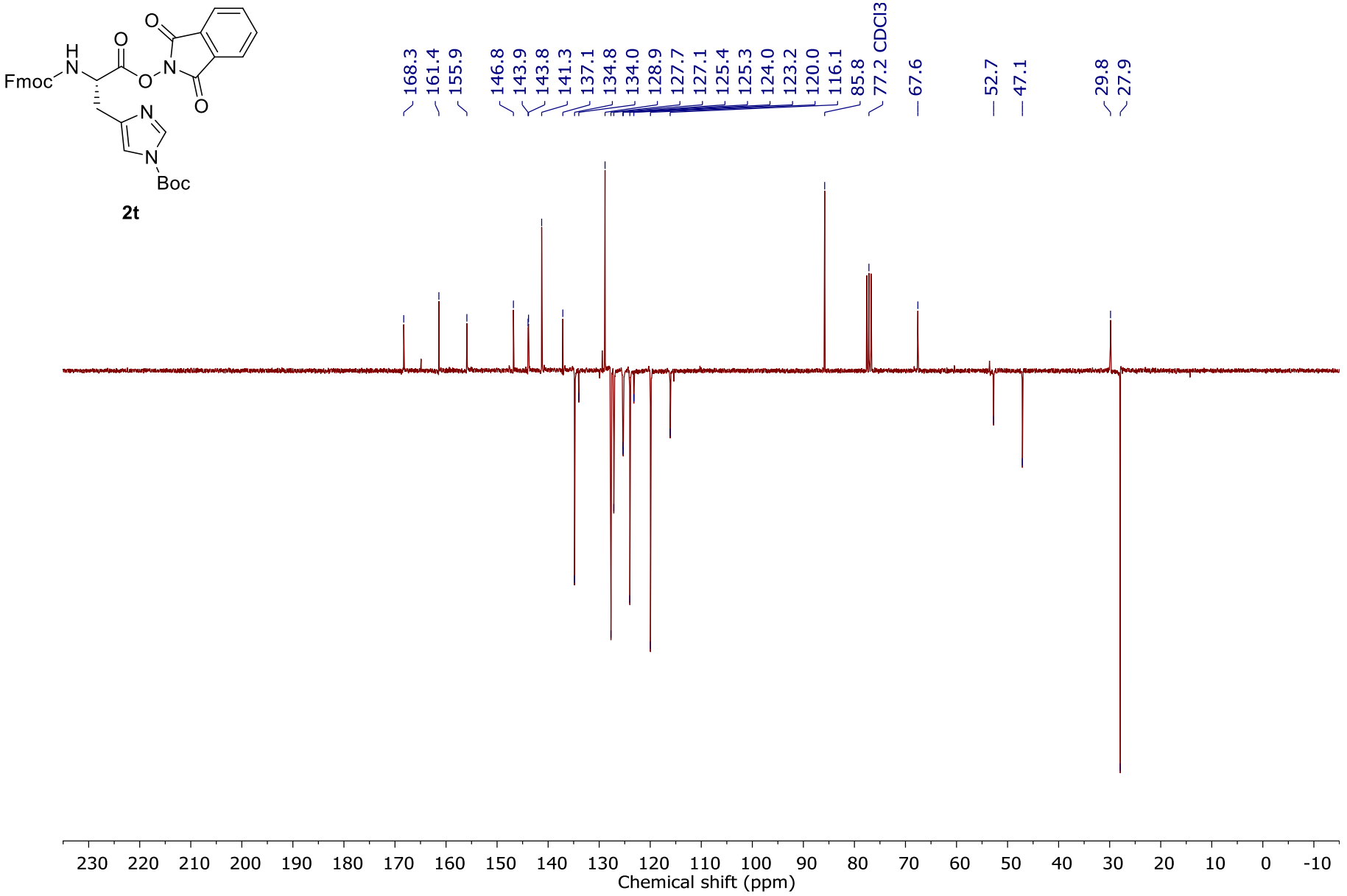

Fmoc
H
N
O
O
N
O
O
O
O
2r
168.5
161.5
155.4
155.0
143.9
143.7
141.4
135.0
130.3
129.2
128.9
127.8
127.2
125.2
125.2
124.4
124.2
120.1
78.6
77.2 CDCl3
67.3
53.2
47.2
37.6
29.0
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

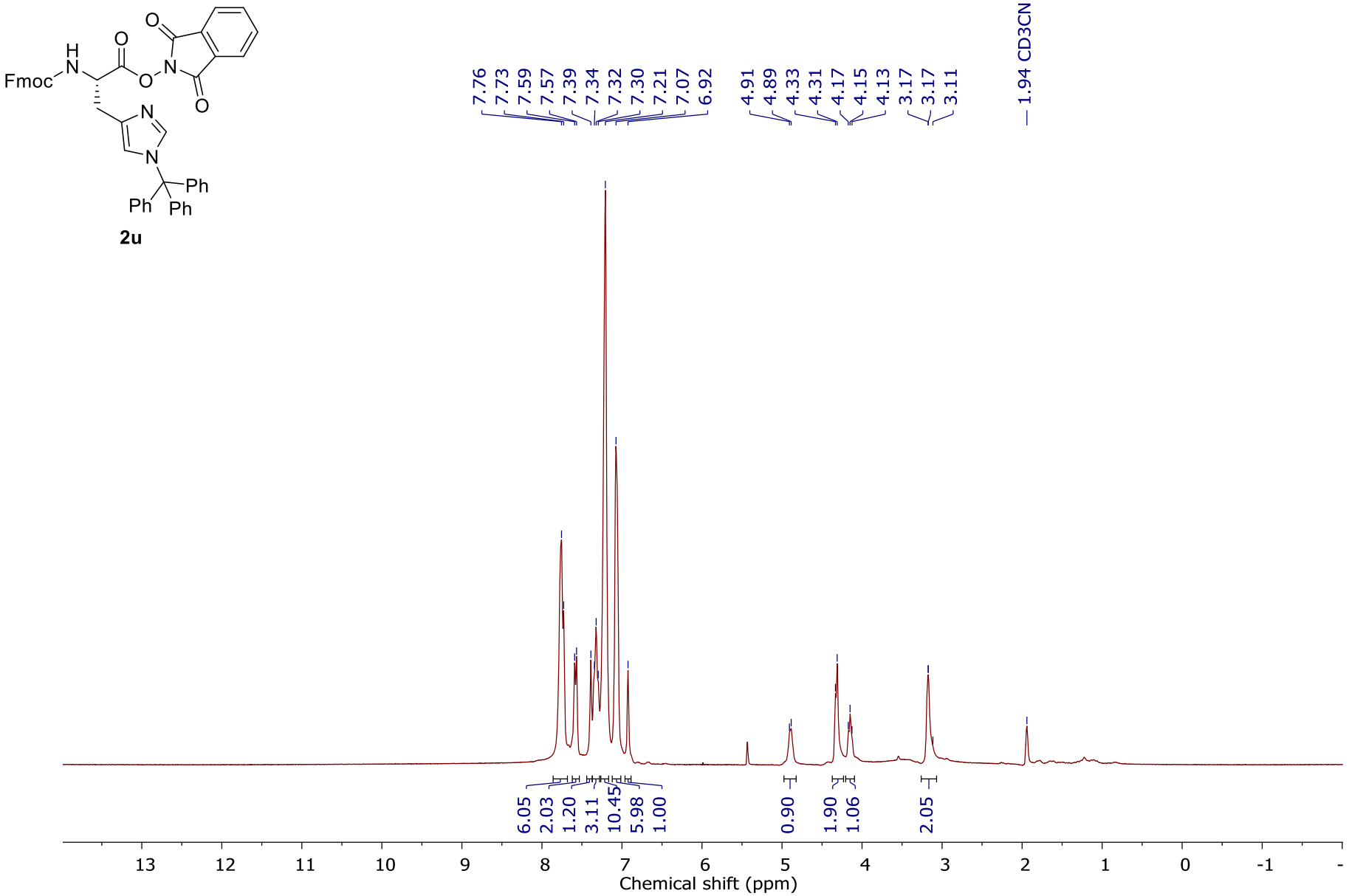

8.24
8.21
7.87
7.85
7.84
7.82
7.81
7.75
7.74
7.73
7.72
7.71
7.65
7.63
7.56
7.53
7.50
7.41
7.40
7.38
7.35
7.31
7.29
7.27
7.26 CDCl3
7.26
5.65
5.62
5.32
5.31
5.28
4.46
4.42
4.41
4.39
4.35
4.22
4.19
4.17
3.62
3.60
3.57
3.55
3.50
3.48
3.45
3.43
1.71
Fmoc
2s
1.00
3.15
4.45
1.11
2.10
3.20
3.15
0.86
0.85
1.94
0.84
1.92
9.15
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

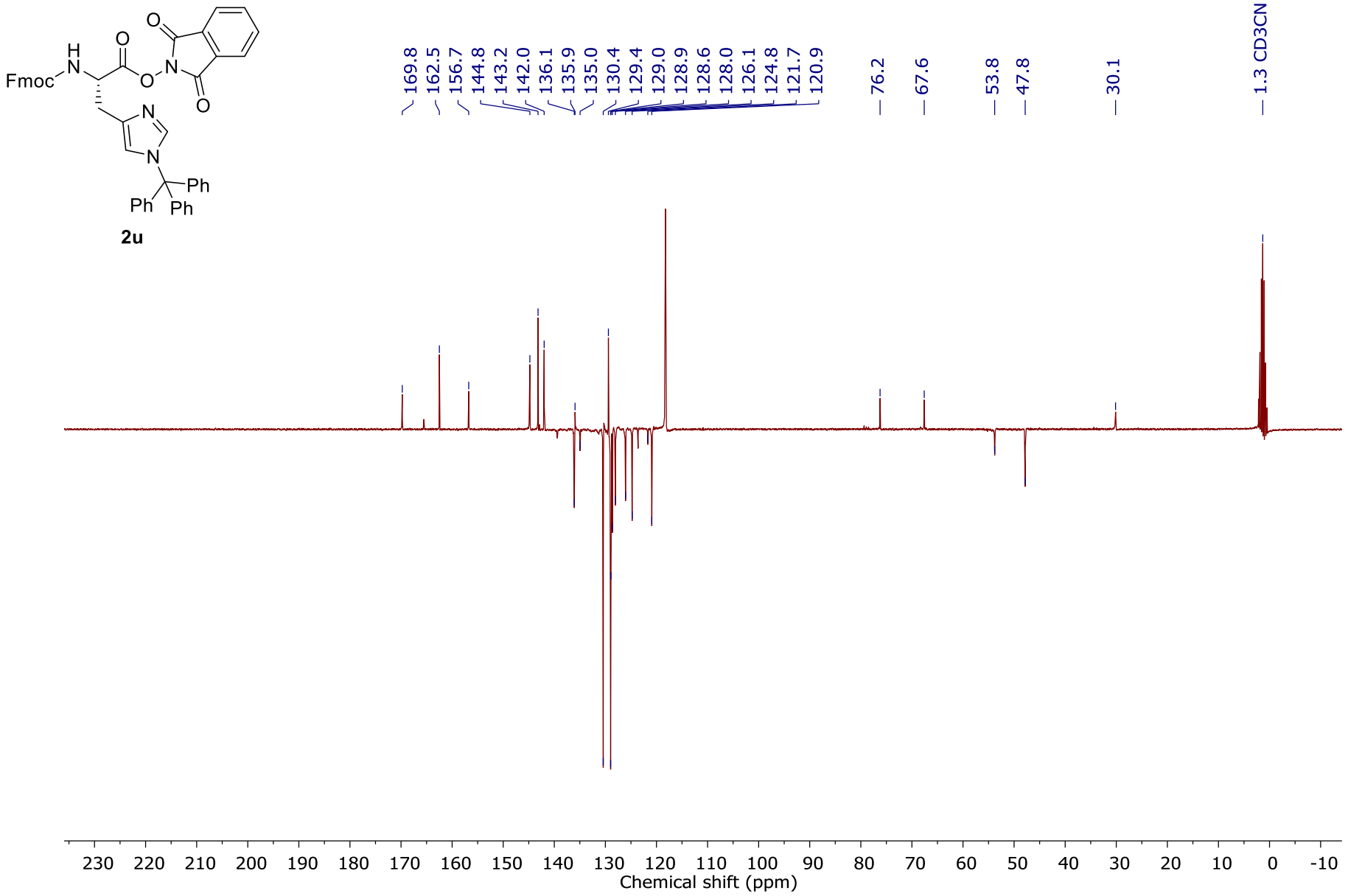

Fmoc
2s
168.5
161.3
155.5
149.5
143.7
143.5
141.2
135.5
134.8
130.5
128.7
127.7
127.1
125.1
124.6
123.9
122.8
119.9
118.6
115.4
113.4
83.6
77.2 CDCl3
67.4
52.9
46.9
28.1
27.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


8.09
7.85
7.83
7.82
7.76
7.74
7.72
7.63
7.61
7.59
7.49
7.40
7.37
7.35
7.31
7.29
7.26
7.26 CDCl3
6.67
6.64
5.16
5.14
5.11
5.10
4.43
4.40
4.37
4.36
4.32
4.28
4.25
4.23
3.41
3.39
3.36
3.34
3.32
3.29
3.27
1.62
Fmoc
H
N
O
O
O
N
O
O
N
N
Boc
0.87
1.91
4.02
2.04
0.78
2.02
1.87
0.76
0.79
1.81
0.88
1.93
8.52
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

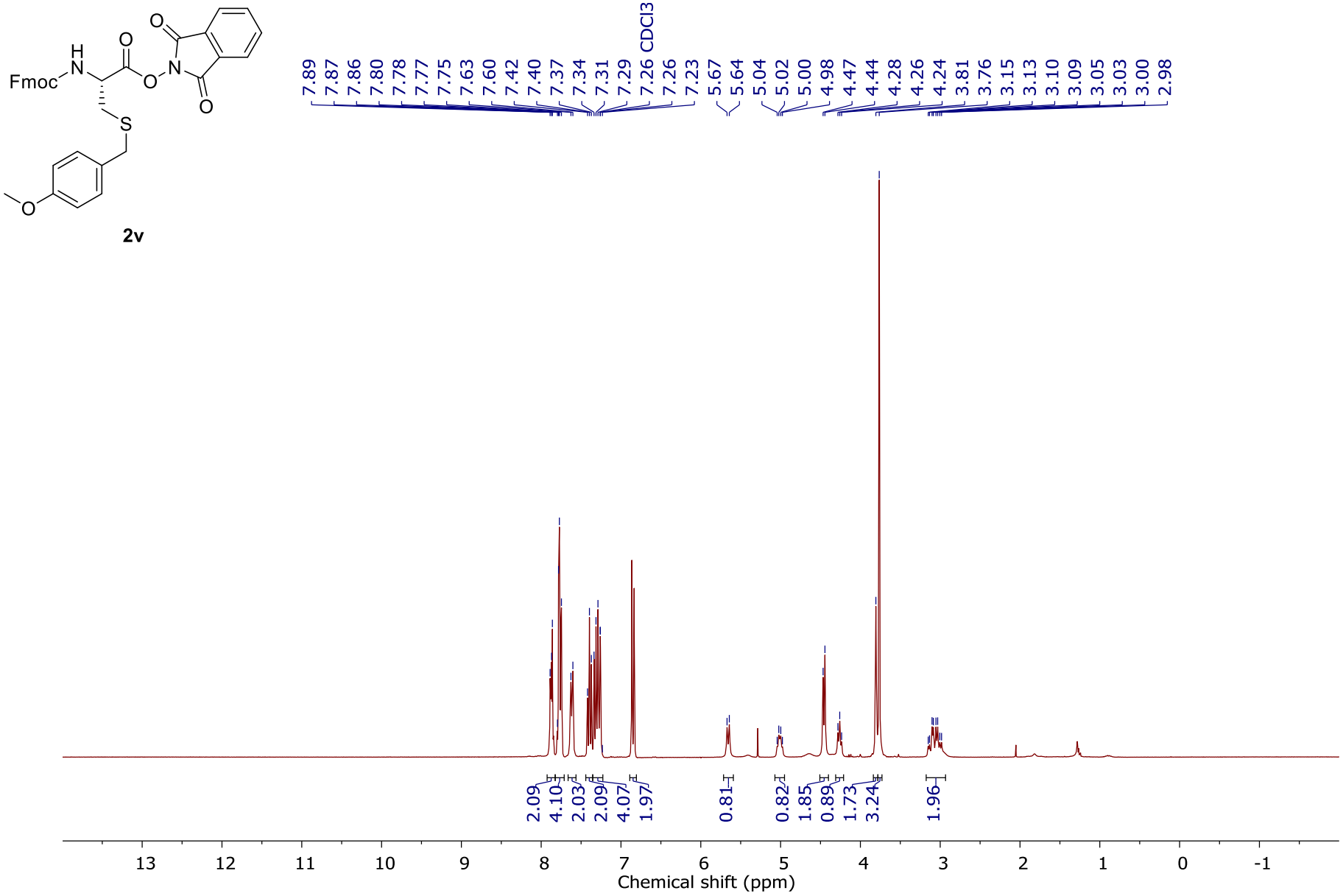
2t

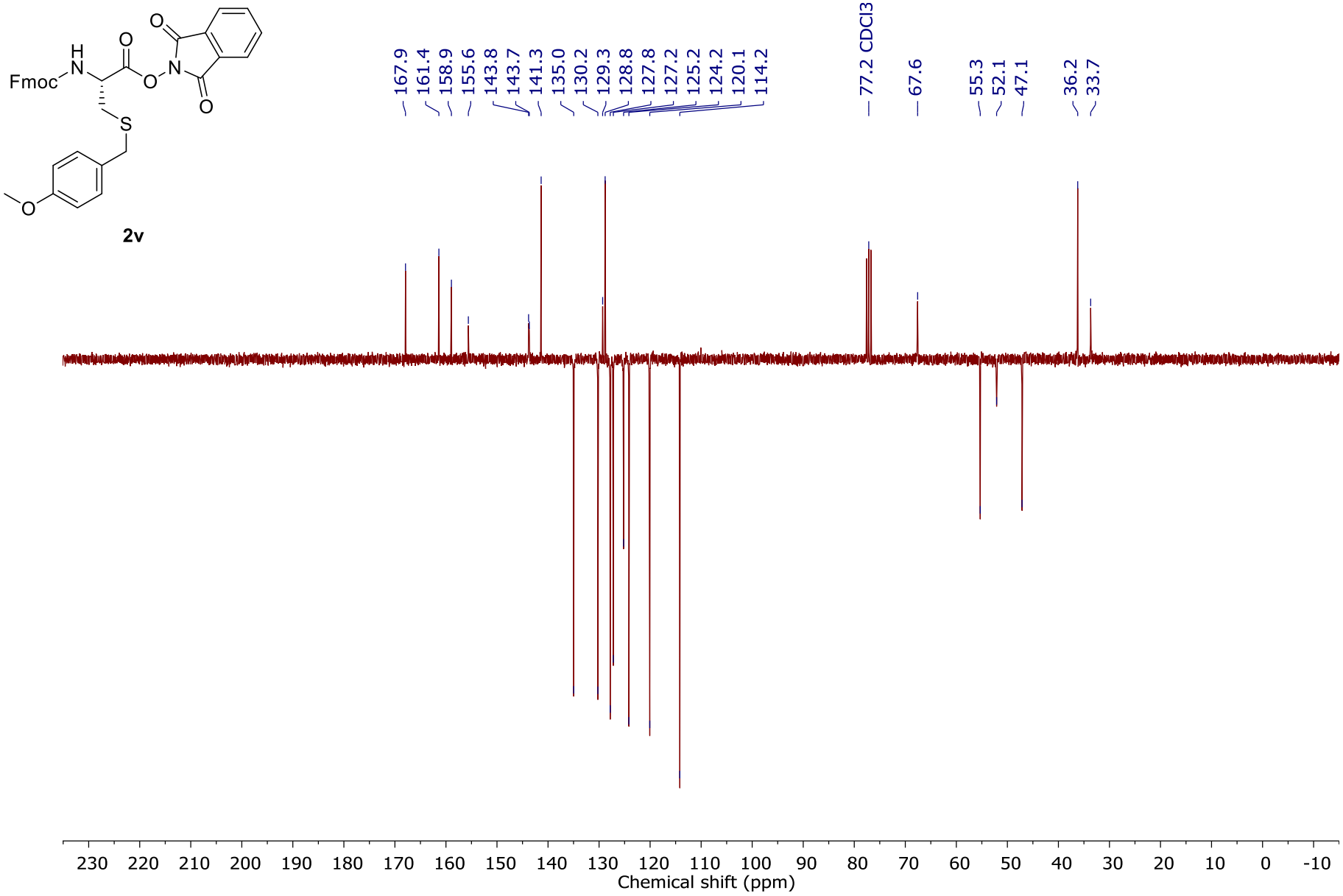

Fmoc
H
N
O
O
N
O
O
N
N
Boc
2t
168.3
161.4
155.9
146.8
143.9
143.8
141.3
137.1
134.8
134.0
128.9
127.7
127.1
125.4
125.3
124.0
123.2
120.0
116.1
85.8
77.2 CDCl3
67.6
52.7
47.1
29.8
27.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

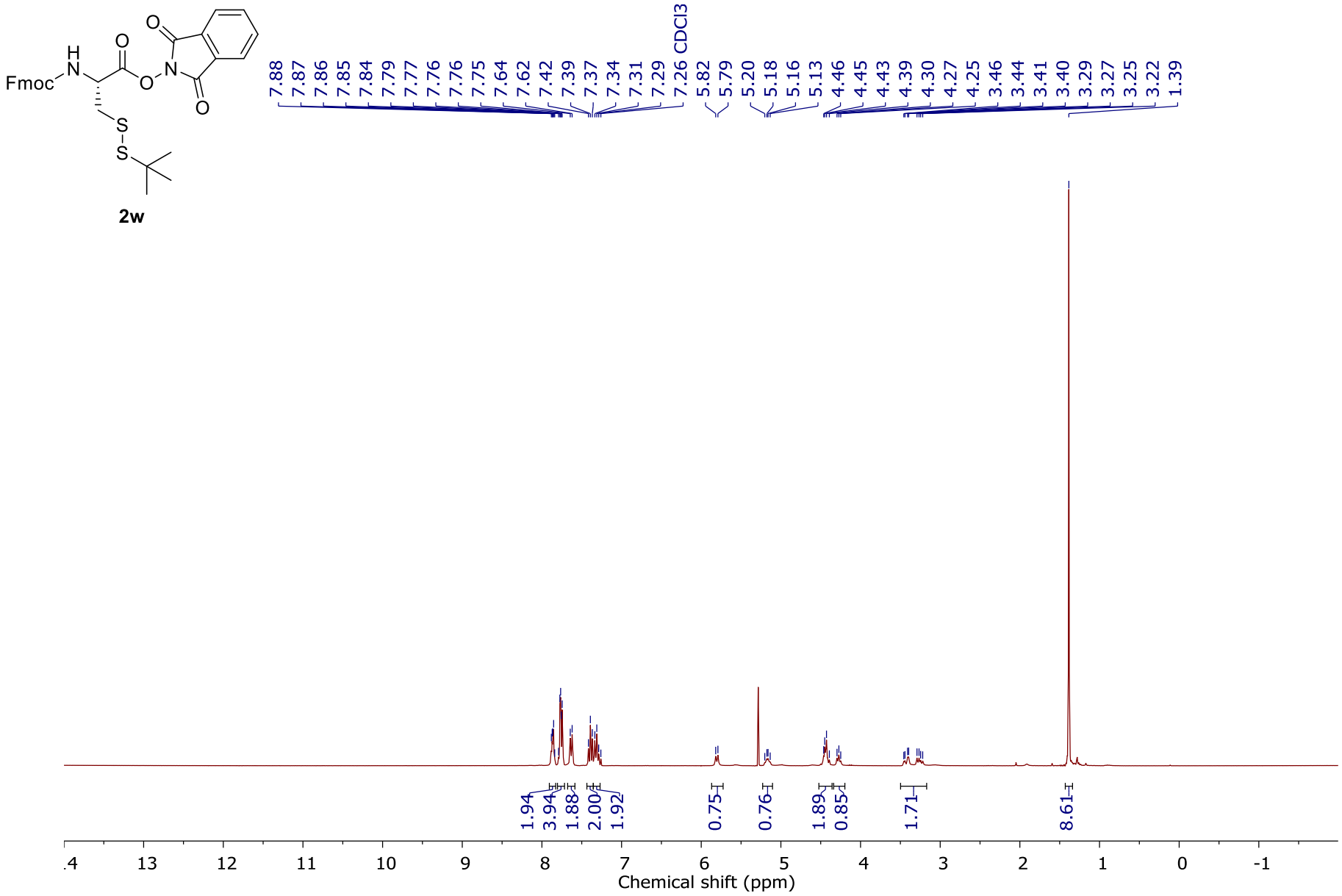

Fmoc
H
N
O
O
N
O
O
N
N
Ph
Ph
Ph
2u
7.76
7.73
7.59
7.57
7.39
7.34
7.32
7.30
7.21
7.07
6.92
4.91
4.89
4.33
4.31
4.17
4.15
4.13
3.17
3.17
3.11
1.94 CD3CN
6.05
2.03
1.20
3.11
10.45
5.98
1.00
0.90
1.90
1.06
2.05
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-
Chemical shift (ppm)

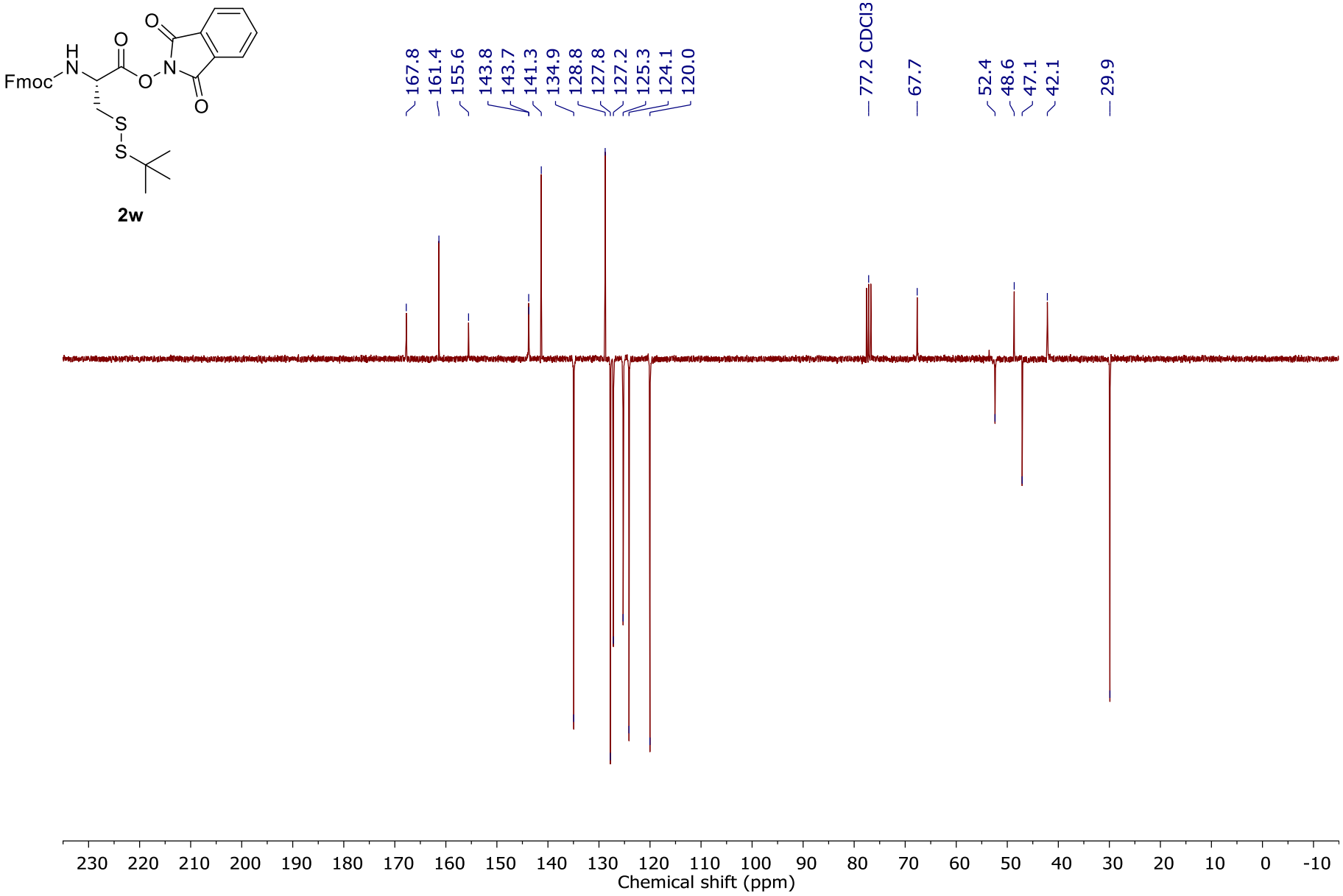

Fmoc
H
N
O
O
N
O
O
N
N
Ph
Ph
Ph
169.8
162.5
156.7
144.8
143.2
142.0
136.1
135.9
135.0
130.4
129.4
129.0
128.9
128.6
128.0
126.1
124.8
121.7
120.9
76.2
67.6
53.8
47.8
30.1
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

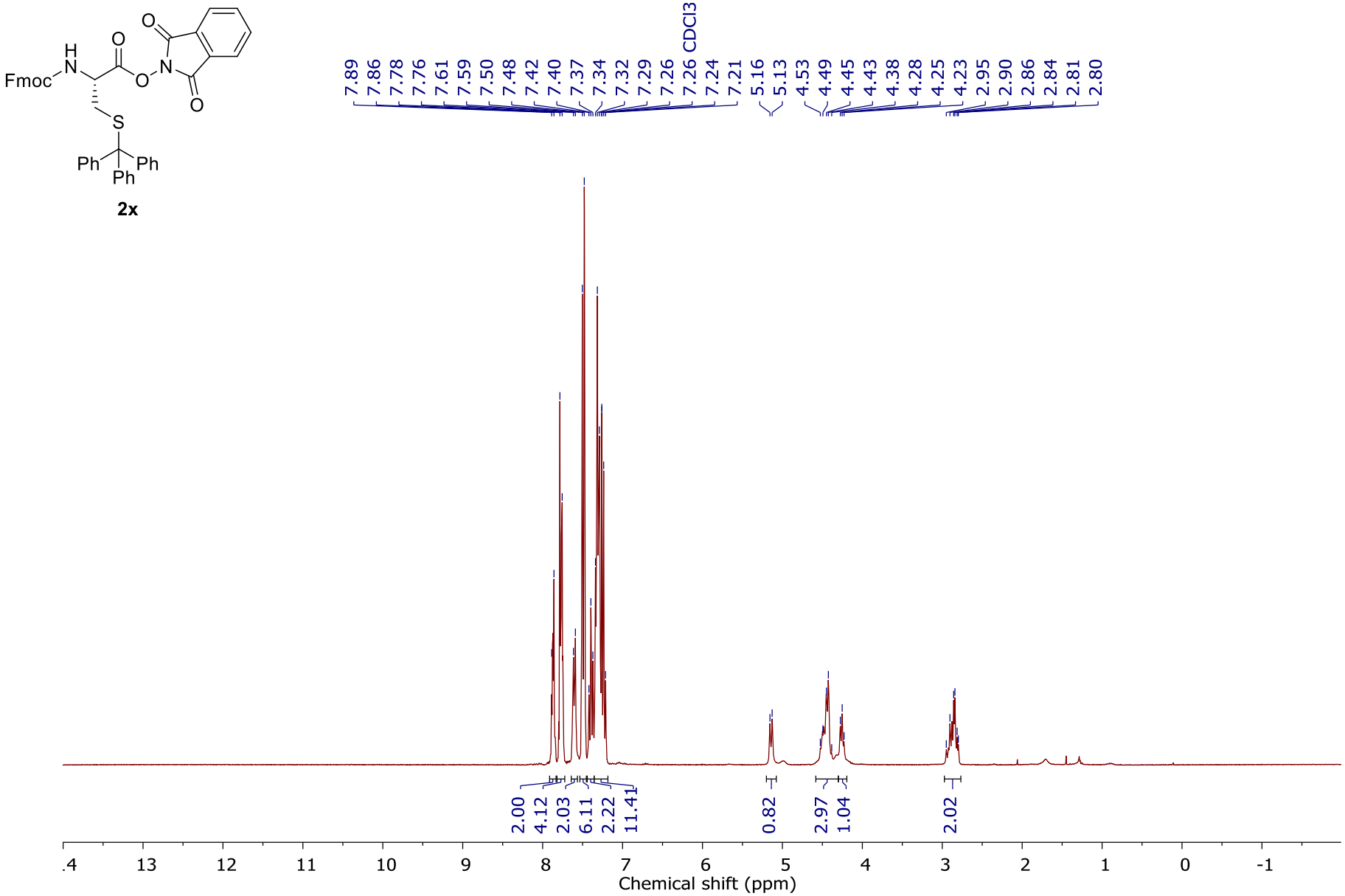
2u

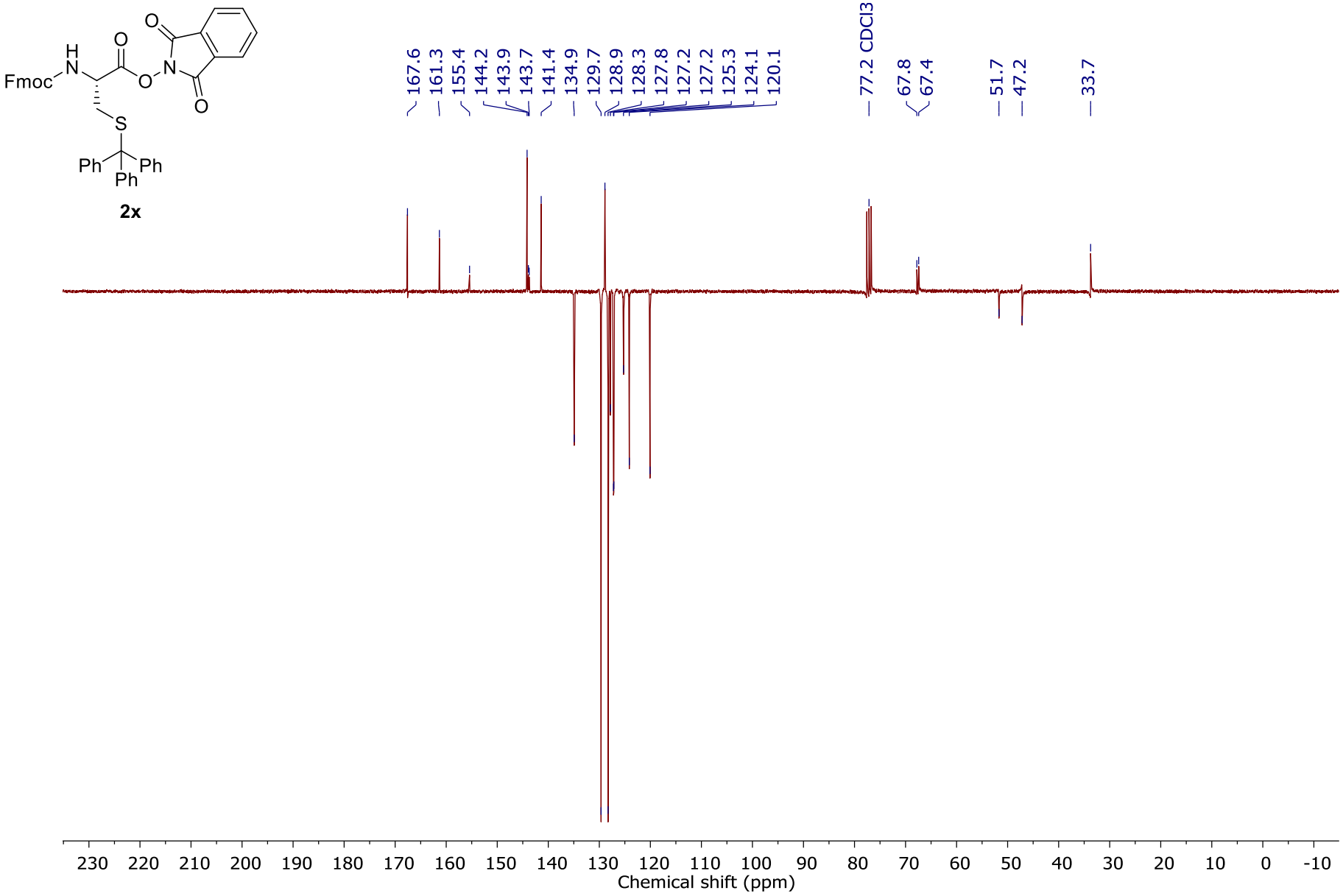

Fmoc
H
N
O
O
N
O
O
O
S
O
2v
7.89
7.87
7.86
7.80
7.78
7.77
7.75
7.63
7.60
7.42
7.40
7.37
7.34
7.31
7.29
7.26 CDCl3
7.26
7.23
5.67
5.64
5.04
5.02
5.00
4.98
4.47
4.44
4.28
4.26
4.24
3.81
3.76
3.15
3.13
3.10
3.09
3.05
3.03
3.00
2.98
2.09
4.10
2.03
2.09
4.07
1.97
0.81
0.82
1.85
0.89
1.73
3.24
1.96
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
O
O
N
O
O
O
S
O
2v
167.9
161.4
158.9
155.6
143.8
143.7
141.3
135.0
130.2
129.3
128.8
127.8
127.2
125.2
124.2
120.1
114.2
77.2 CDCl3
67.6
55.3
52.1
47.1
36.2
33.7
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
Chemical shift (ppm)

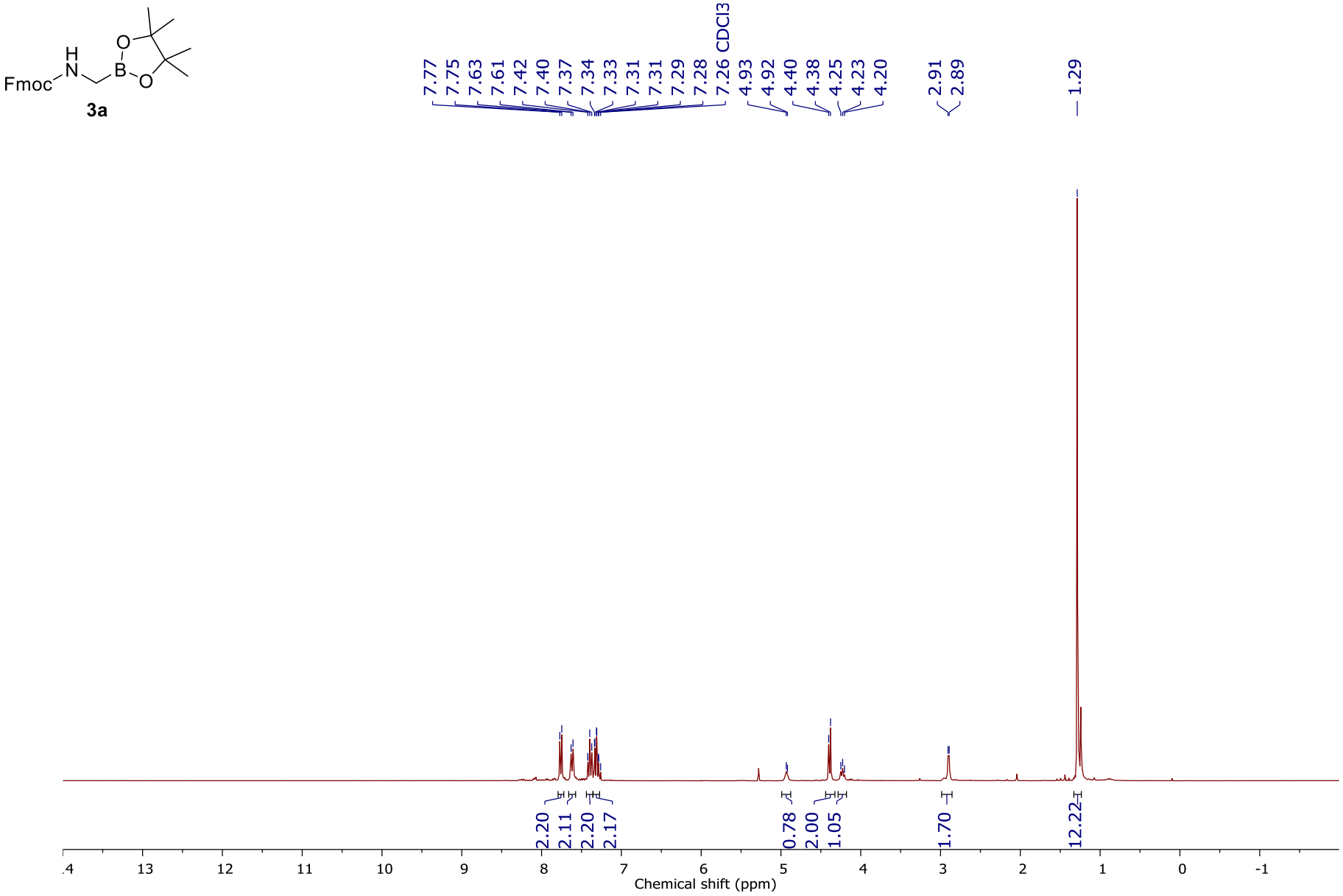

Fmoc
H
N
O
O
N
O
O
O
S
S
2w
7.88
7.87
7.86
7.85
7.84
7.79
7.77
7.76
7.76
7.75
7.64
7.62
7.42
7.39
7.37
7.34
7.31
7.29
7.26 CDCl3
5.82
5.79
5.20
5.18
5.16
5.13
4.46
4.45
4.43
4.39
4.30
4.27
4.25
3.46
3.44
3.41
3.40
3.29
3.27
3.25
3.22
1.39
1.94
3.94
1.88
2.00
1.92
0.75
0.76
1.89
0.85
1.71
8.61
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

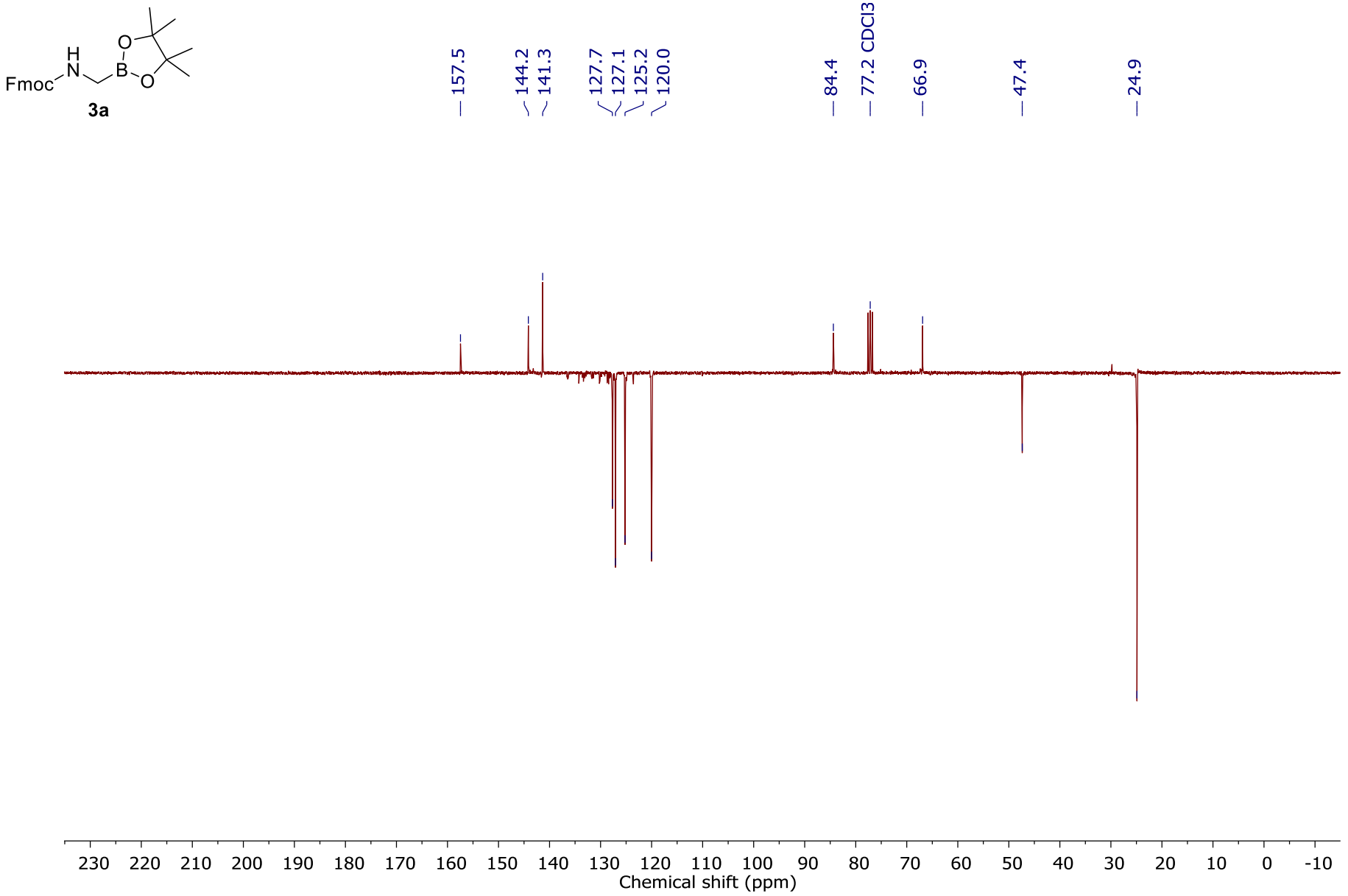

Fmoc
H
N
O
O
N
O
O
S
S
2w
167.8
161.4
155.6
143.8
143.7
141.3
134.9
128.8
127.8
127.2
125.3
124.1
120.0
77.2 CDCl3
67.7
52.4
48.6
47.1
42.1
29.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

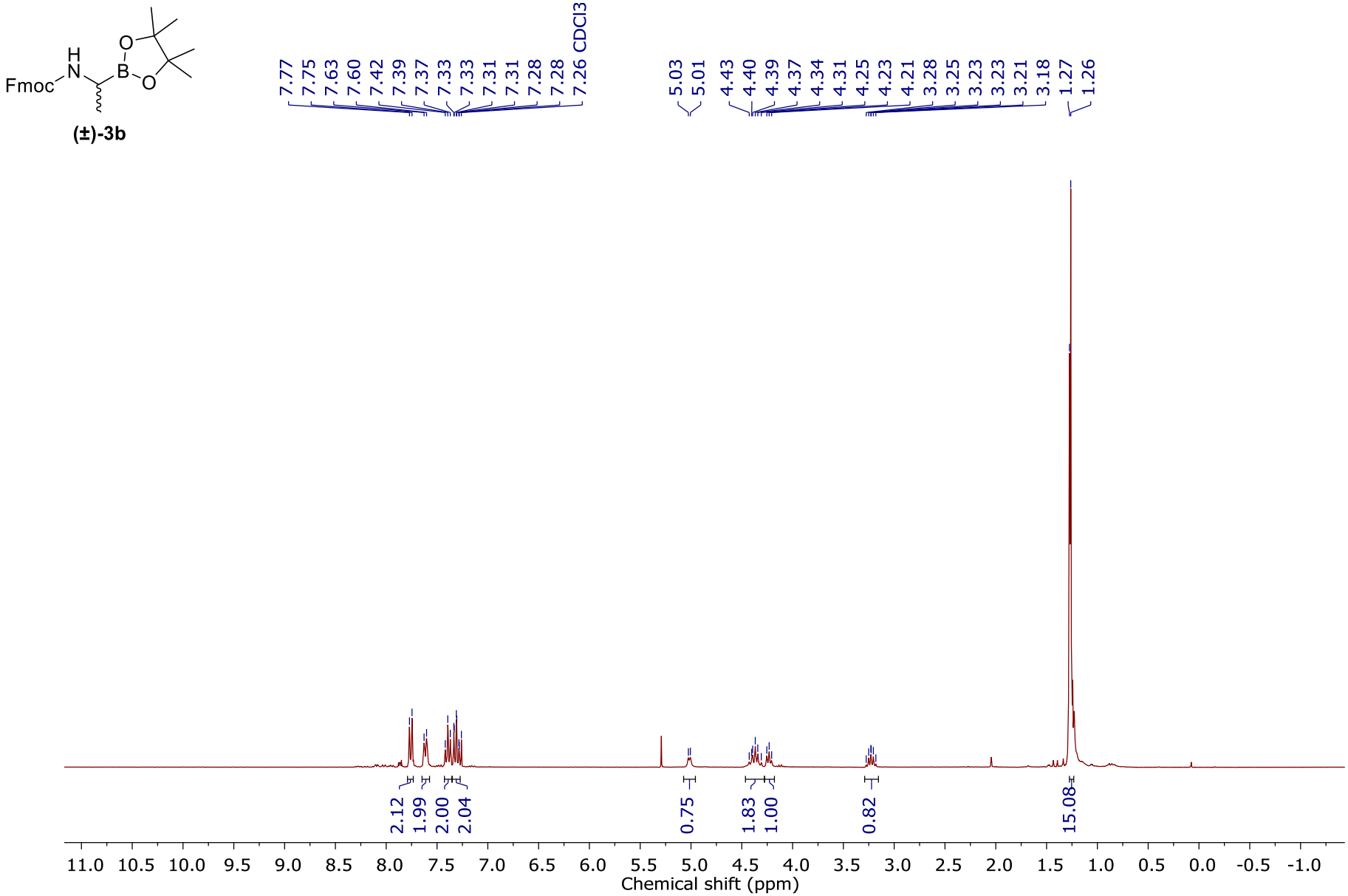

Fmoc
H
N
O
O
N
O
O
S
Ph
Ph
Ph
2x
7.89
7.86
7.78
7.76
7.61
7.59
7.50
7.48
7.42
7.40
7.37
7.34
7.32
7.29
7.26
7.26 CDCl3
7.24
7.21
5.16
5.13
4.53
4.49
4.45
4.43
4.38
4.28
4.25
4.23
2.95
2.90
2.86
2.84
2.81
2.80
2.00
4.12
2.03
6.11
2.22
11.41
0.82
2.97
1.04
2.02
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

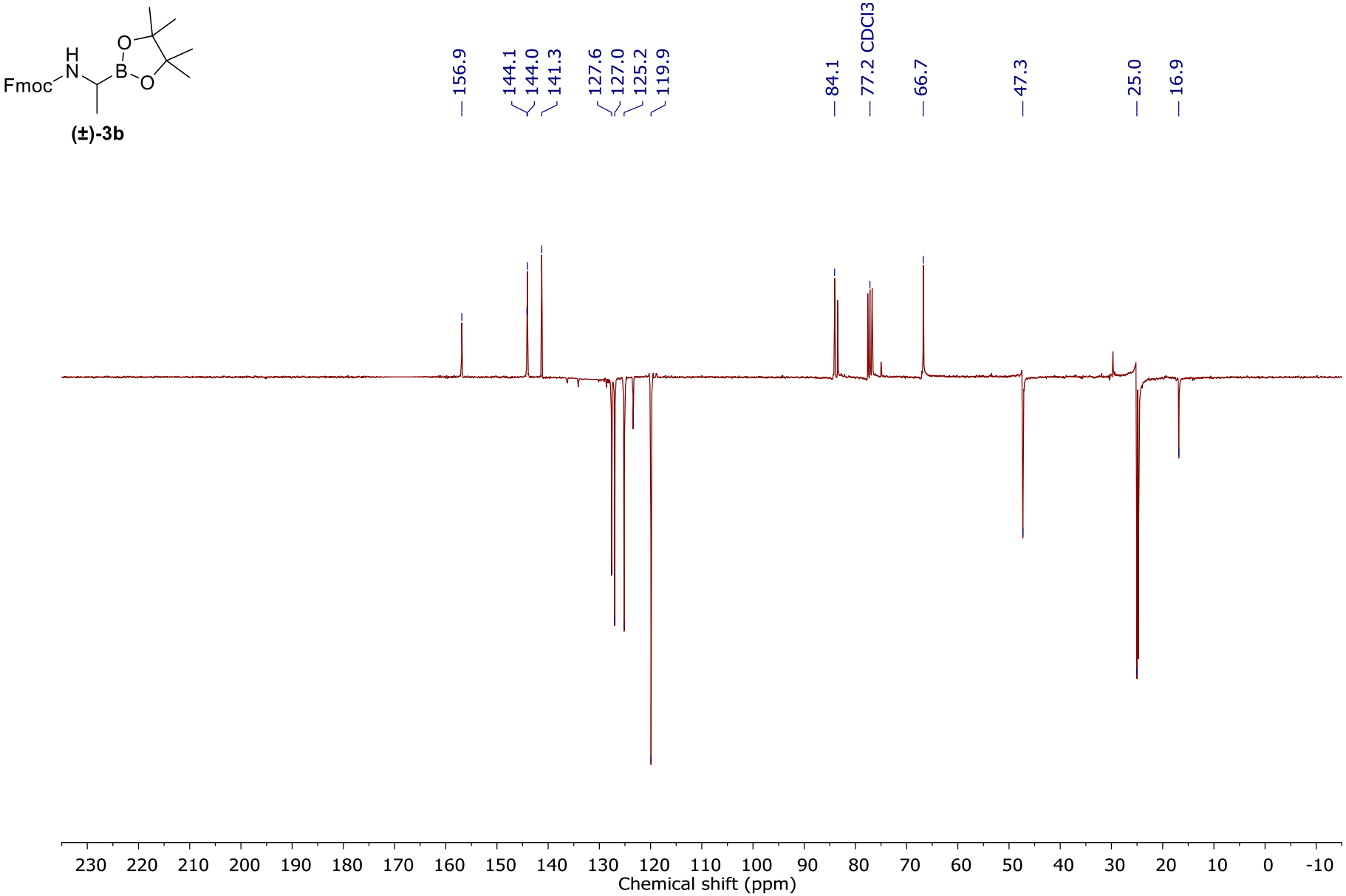

Fmoc
H
N
O
O
N
O
O
S
Ph
Ph
Ph
2x
167.6
161.3
155.4
144.2
143.9
143.7
141.4
134.9
129.7
128.9
128.3
127.8
127.2
127.2
125.3
124.1
120.1
77.2 CDCl3
67.8
67.4
51.7
47.2
33.7
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

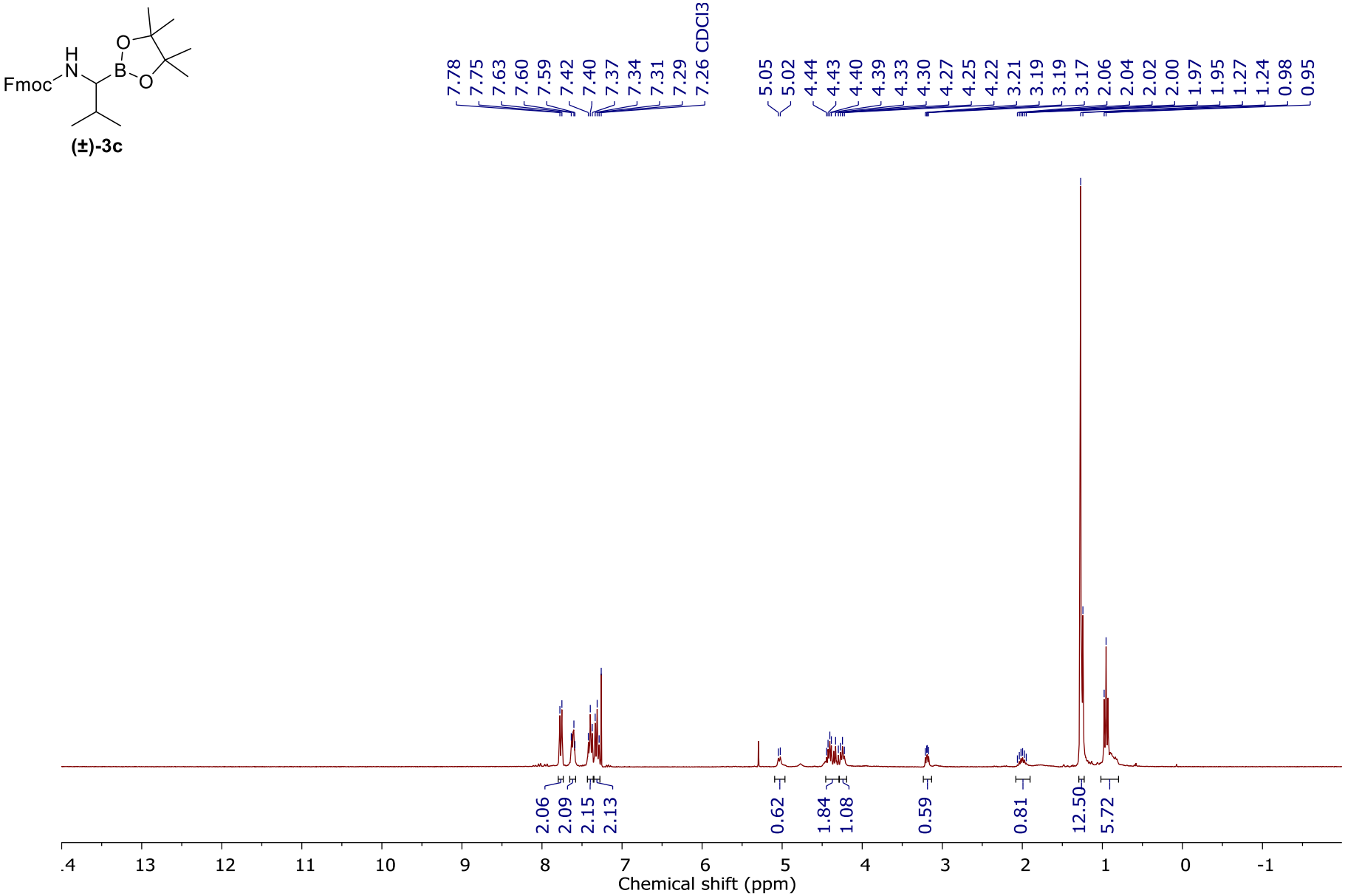
NMR spectra of α-aminopinacolyl boronates

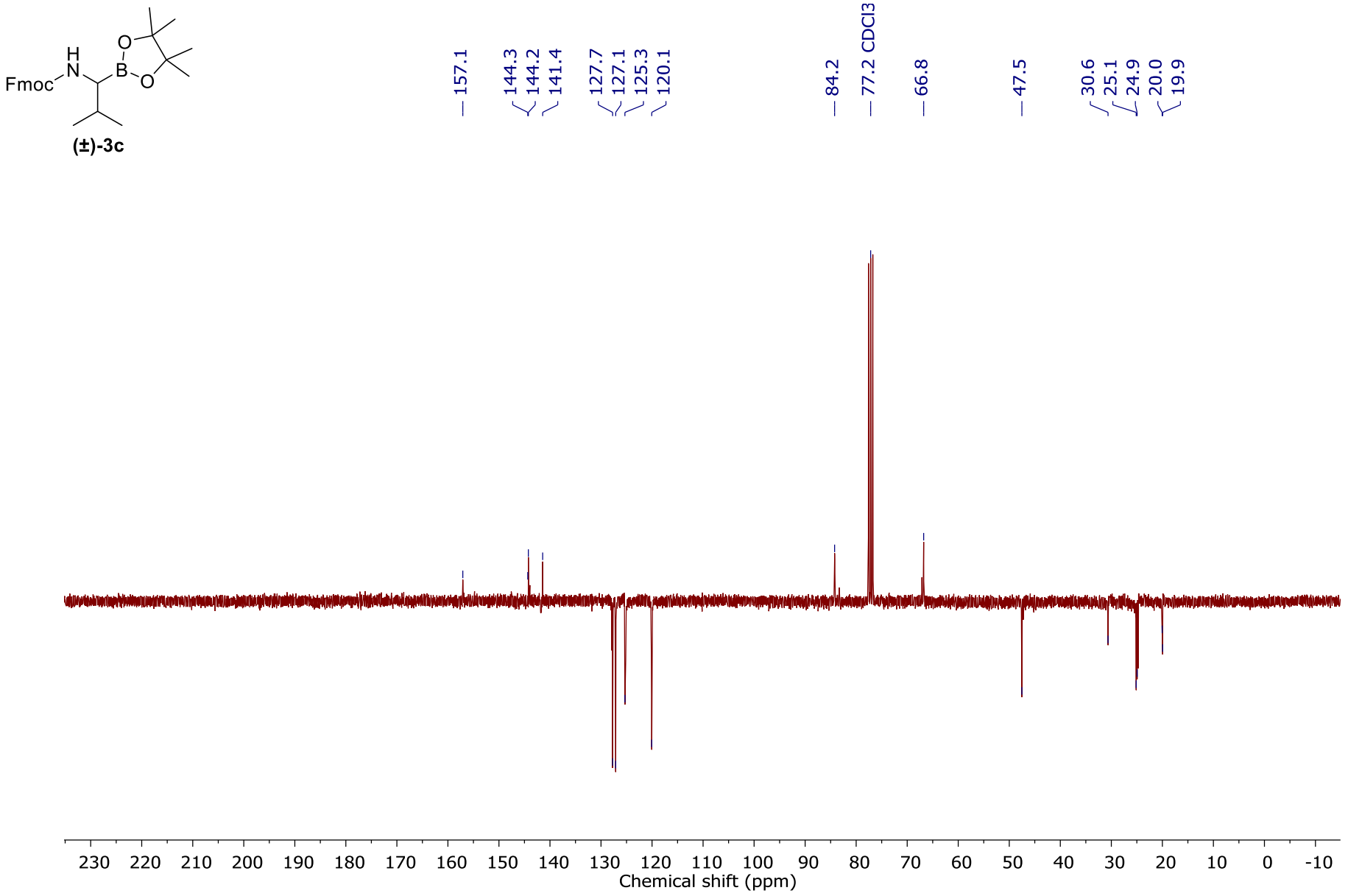

Fmoc
H
N
O
B
O
3a
7.77
7.75
7.63
7.61
7.42
7.40
7.37
7.34
7.33
7.31
7.31
7.29
7.28
7.26 CDCl3
4.93
4.92
4.40
4.38
4.25
4.23
4.20
2.91
2.89
1.29
2.20
2.11
2.20
2.17
0.78
2.00
1.05
1.70
12.22
Chemical shift (ppm)

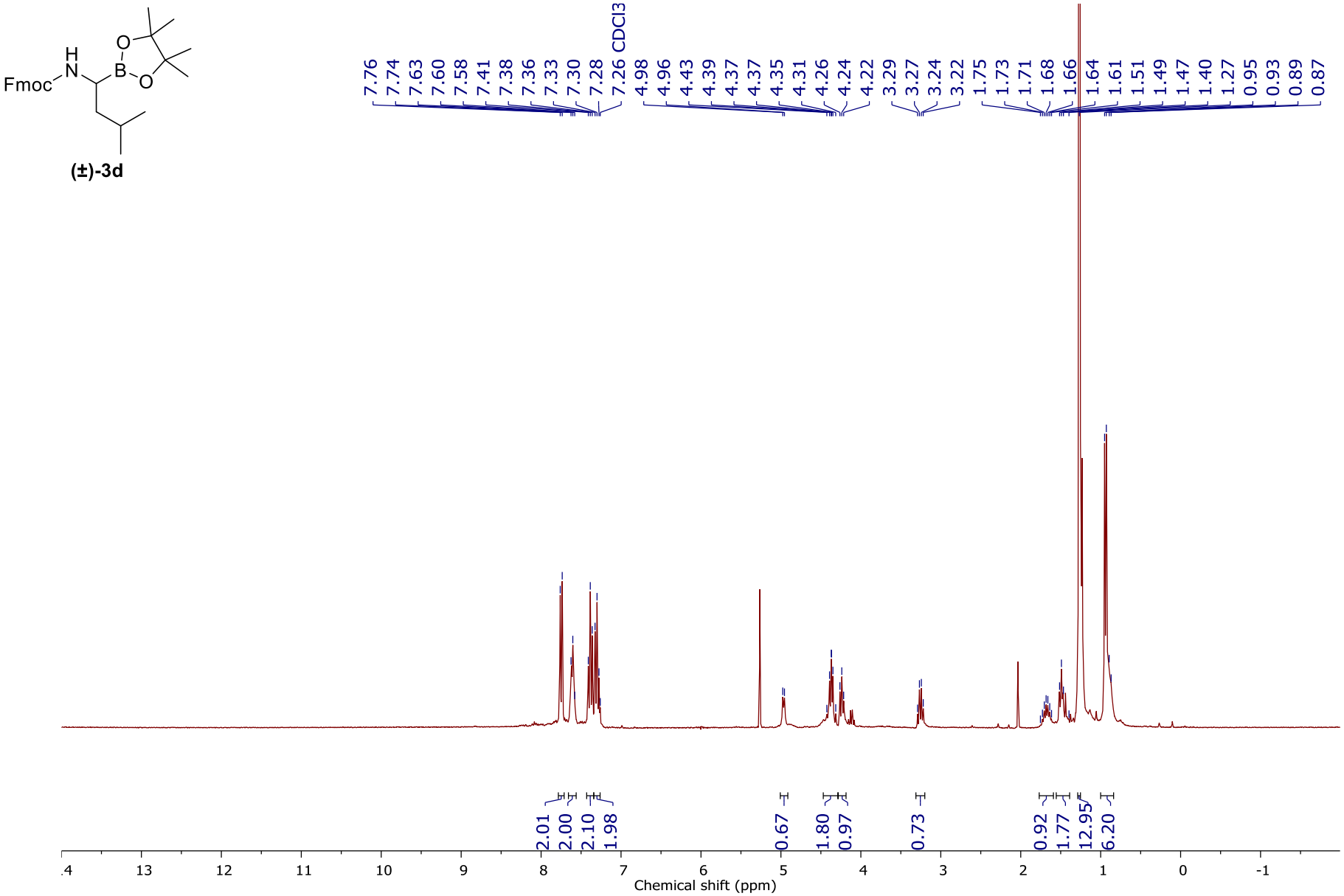

Fmoc
H
N
O
B
O
3a
157.5
144.2
141.3
127.7
127.1
125.2
120.0
84.4
77.2 CDCl3
66.9
47.4
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

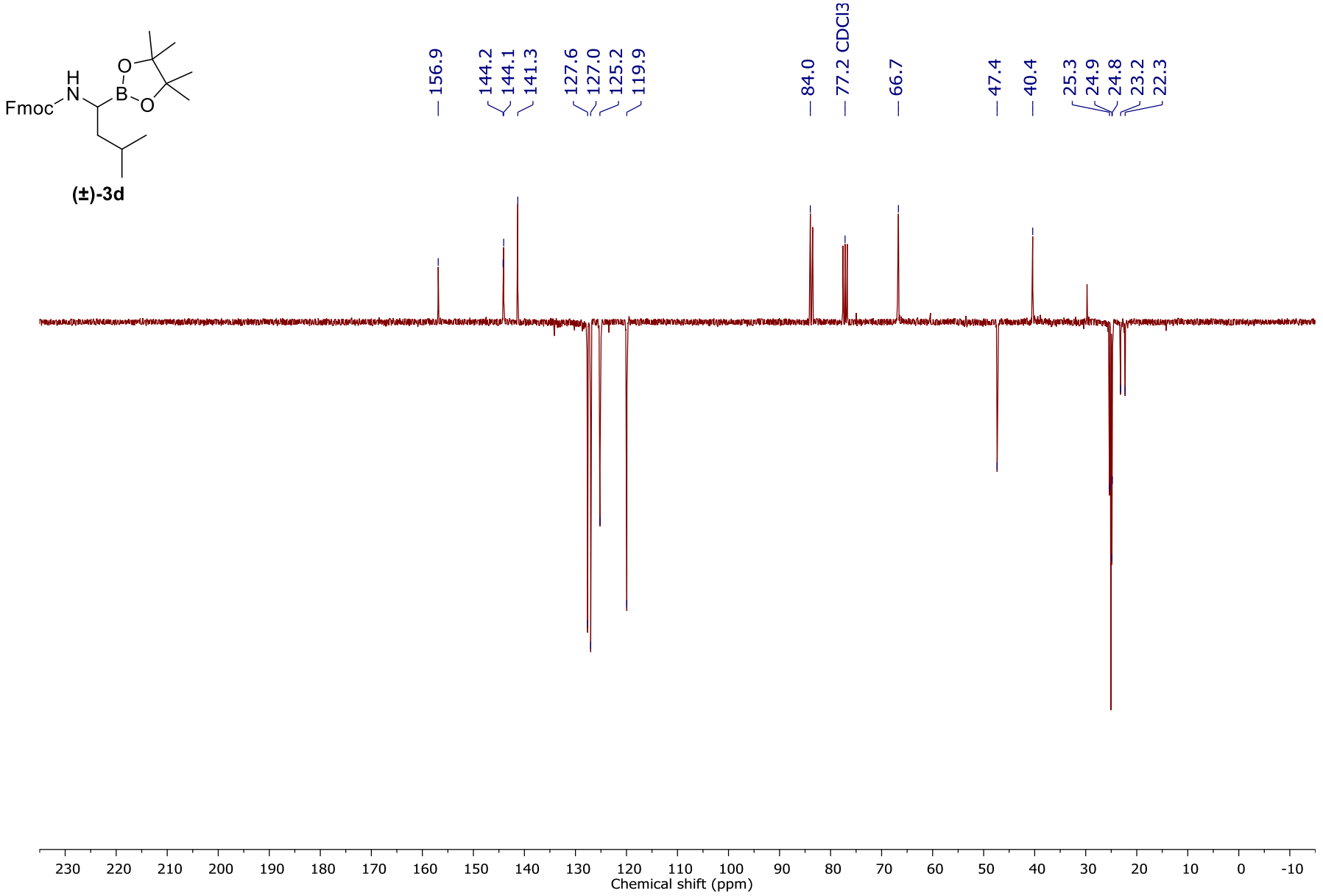

Fmoc
H
N
O
B
O
(±)-3b
7.77
7.75
7.63
7.60
7.42
7.39
7.37
7.33
7.33
7.31
7.31
7.28
7.28
7.26 CDCl3
5.03
5.01
4.43
4.40
4.39
4.37
4.34
4.31
4.25
4.23
4.21
3.28
3.25
3.23
3.23
3.21
3.18
1.27
1.26
2.12
1.99
2.00
2.04
0.75
1.83
1.00
0.82
15.08
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
Chemical shift (ppm)

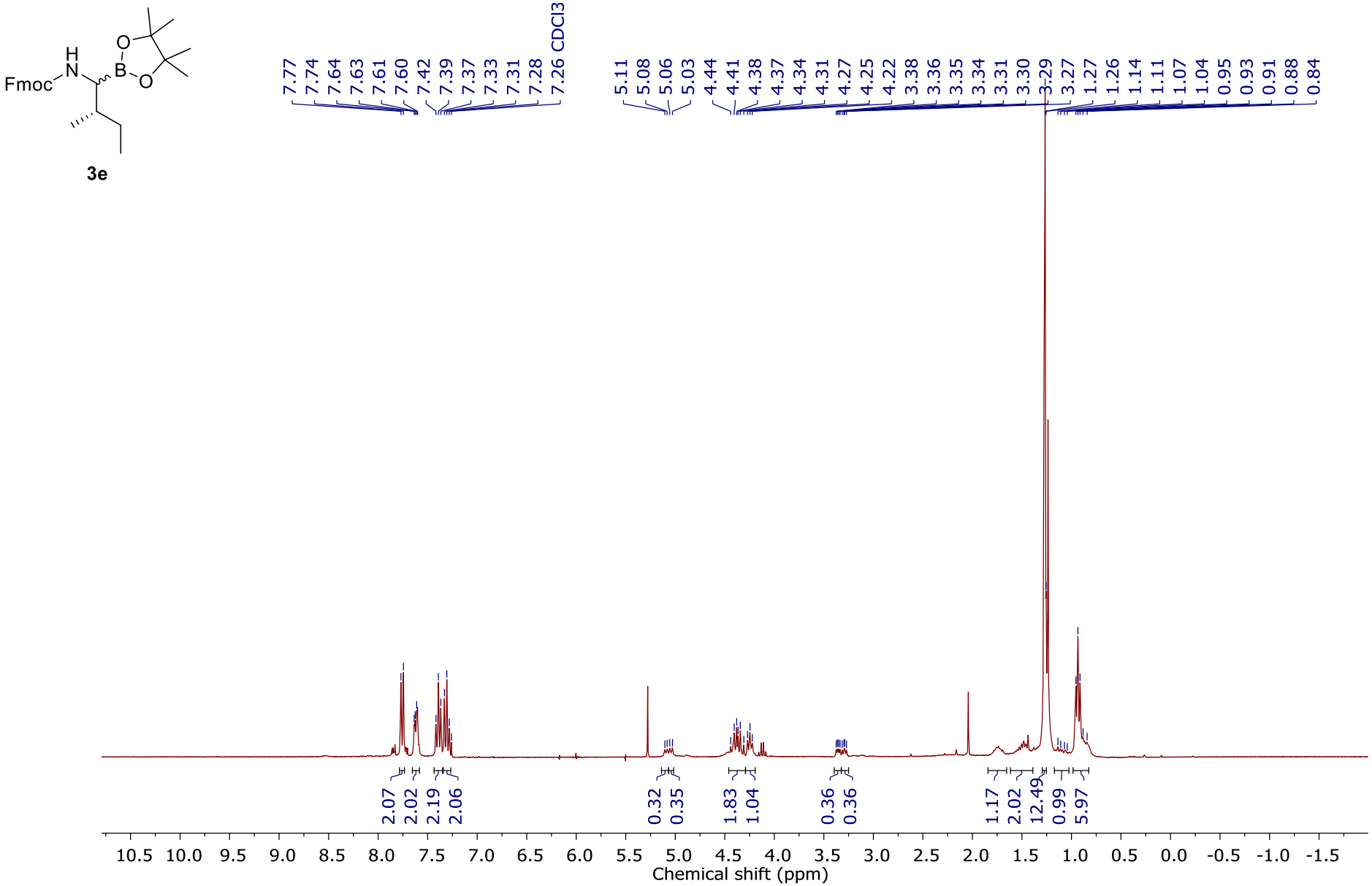

Fmoc
H
N
O
B
O
(±)-3b
156.9
144.1
144.0
141.3
127.6
127.0
125.2
119.9
84.1
77.2 CDCl3
66.7
47.3
25.0
16.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

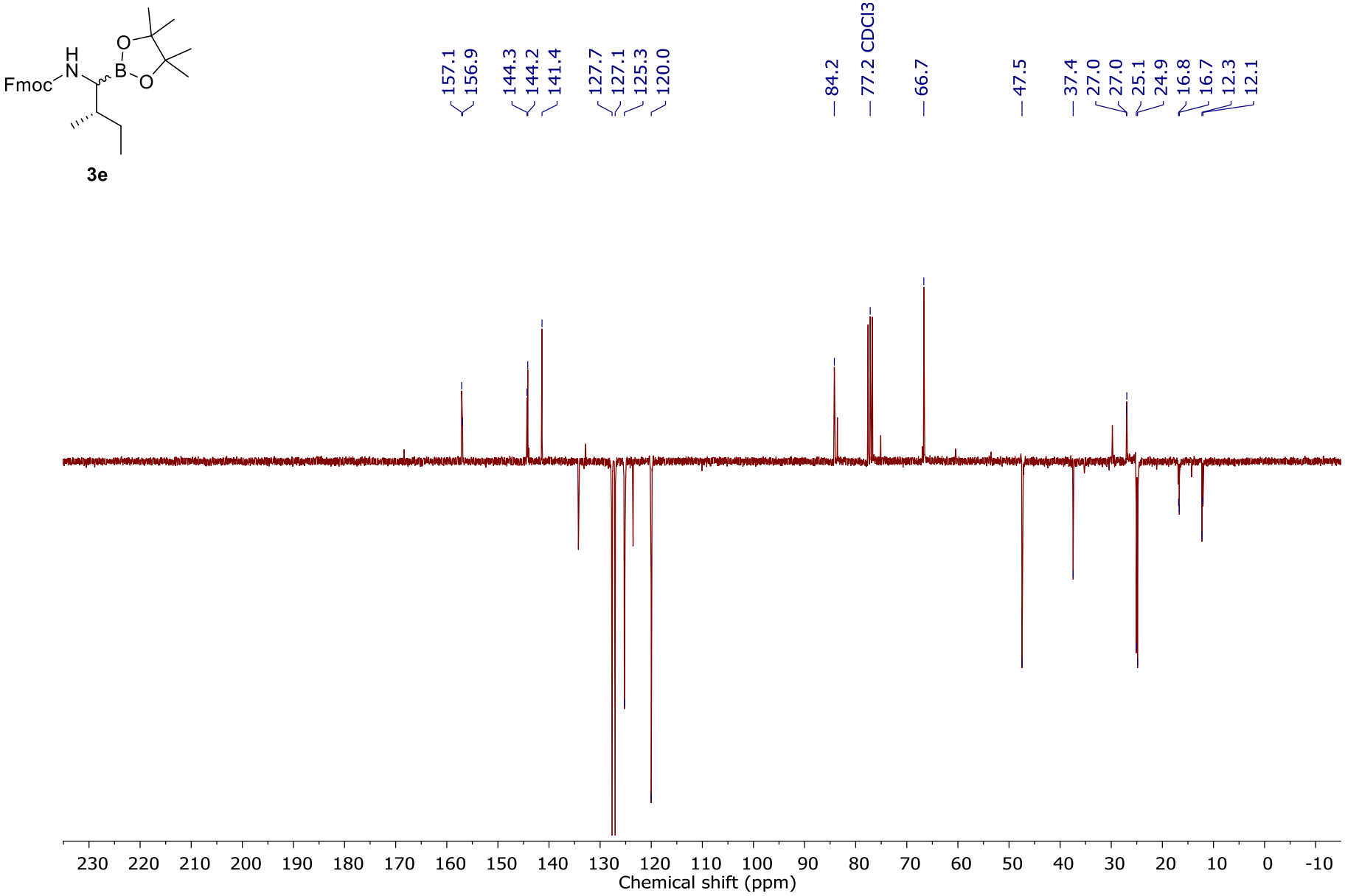

Fmoc
H
N
O
B
O
(±)-3c
7.78
7.75
7.63
7.60
7.59
7.42
7.40
7.37
7.34
7.31
7.29
7.26 CDCl3
5.05
5.02
4.44
4.43
4.40
4.39
4.33
4.30
4.27
4.25
4.22
3.21
3.19
3.19
3.17
2.06
2.04
2.02
2.00
1.97
1.95
1.27
1.24
0.98
0.95
2.06
2.09
2.15
2.13
0.62
1.84
1.08
0.59
0.81
12.50
5.72
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

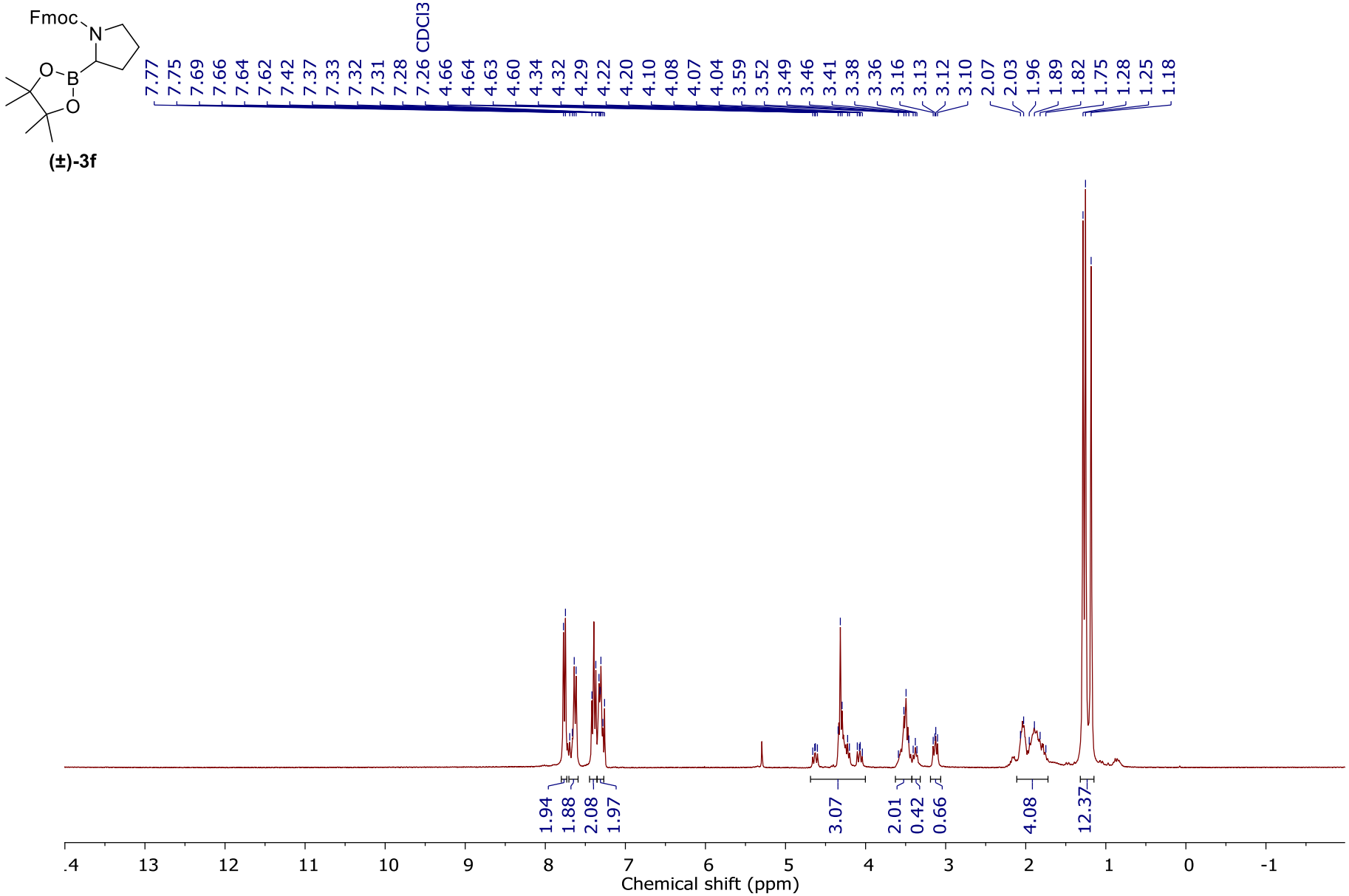

Fmoc
H
N
O
B
O
(±)-3c
157.1
144.3
144.2
141.4
127.7
127.1
125.3
120.1
84.2
77.2 CDCl3
66.8
47.5
30.6
25.1
24.9
20.0
19.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

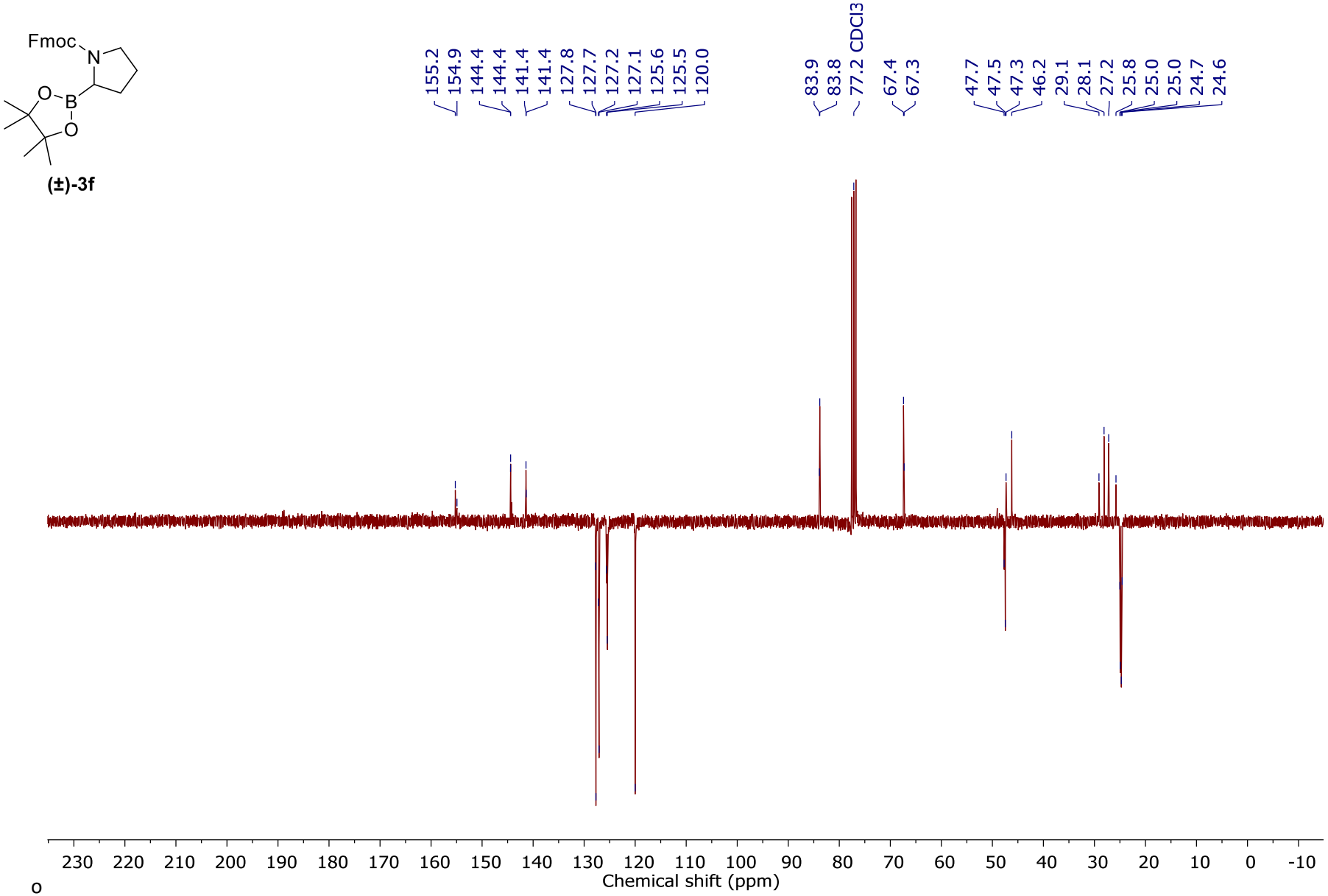

Fmoc
H
N
O
B
O
(±)-3d
7.76
7.74
7.63
7.60
7.58
7.41
7.38
7.36
7.33
7.30
7.28
7.26 CDCl3
4.98
4.96
4.43
4.39
4.37
4.37
4.35
4.31
4.26
4.24
4.22
3.29
3.27
3.24
3.22
1.75
1.73
1.71
1.68
1.66
1.64
1.61
1.51
1.49
1.47
1.40
1.27
0.95
0.93
0.89
0.87
2.01
2.00
2.10
1.98
0.67
1.80
0.97
0.73
0.92
1.77
12.95
6.20
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

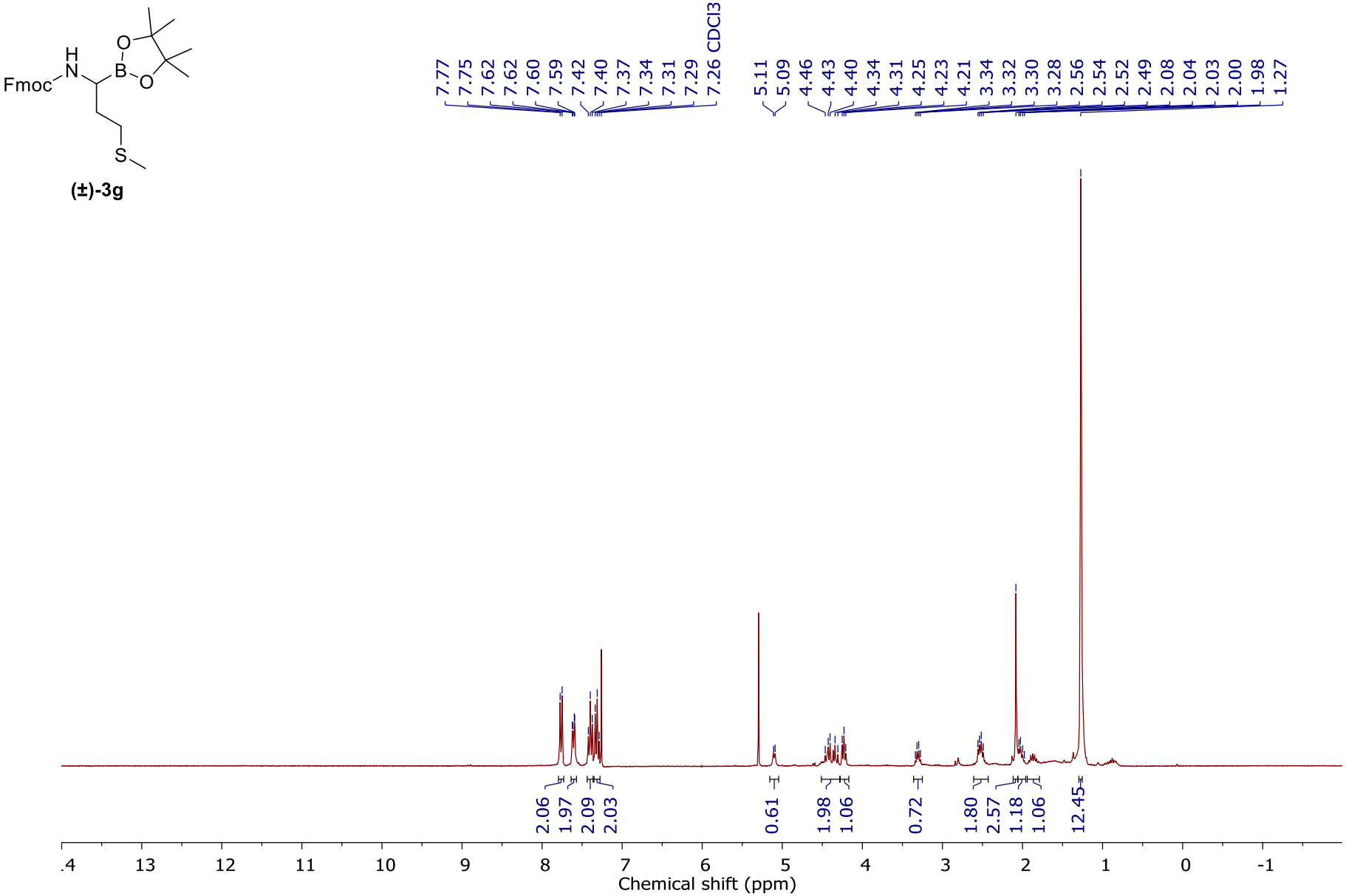

Fmoc
H
N
O
B
O
(±)-3d
156.9
144.2
144.1
141.3
127.6
127.0
125.2
119.9
84.0
77.2 CDCl3
66.7
47.4
40.4
25.3
24.9
24.8
23.2
22.3
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

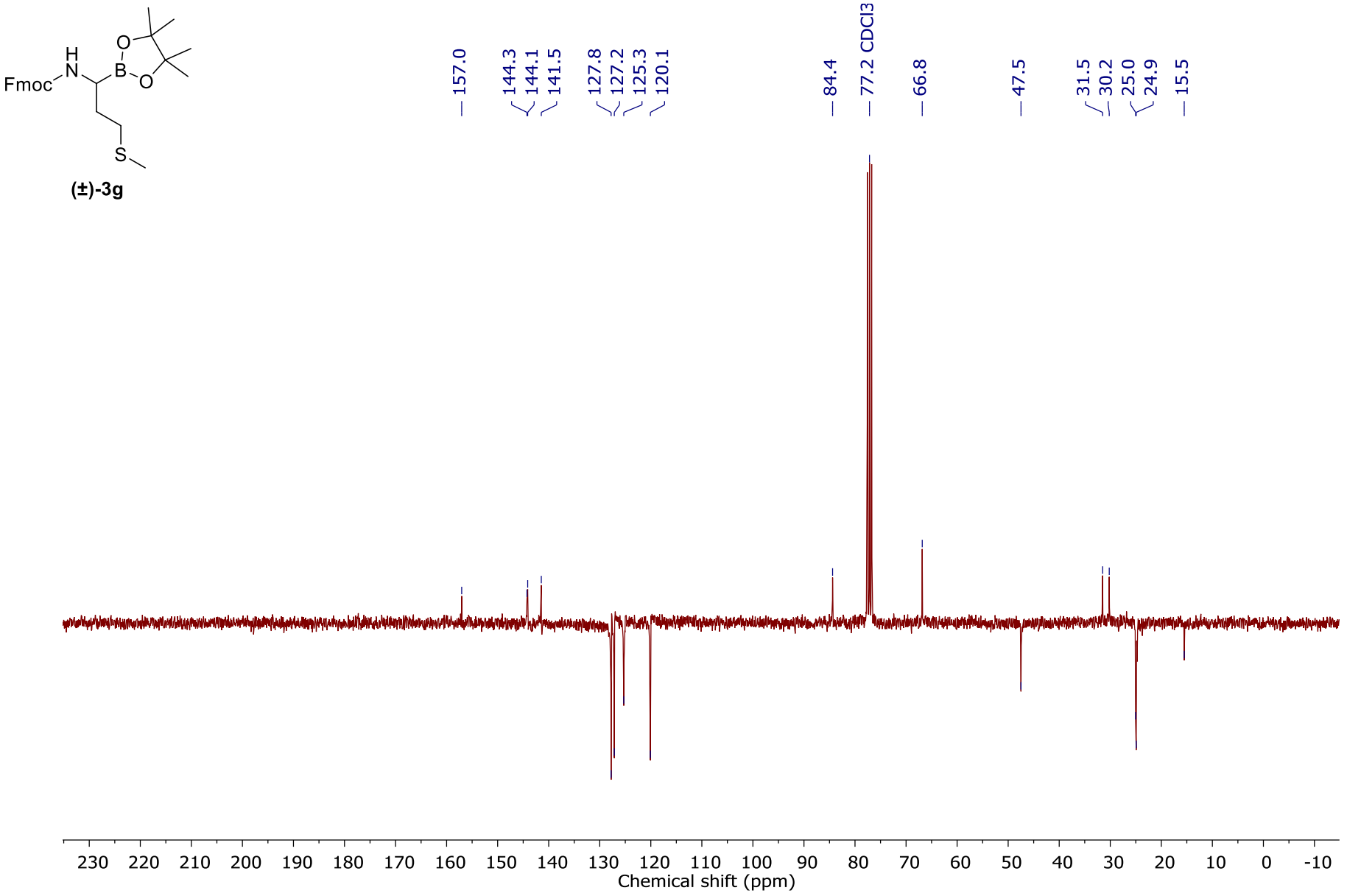

Fmoc
H
N
O
B
O
3e
7.77
7.74
7.64
7.63
7.61
7.60
7.42
7.39
7.37
7.33
7.31
7.28
7.26 CDCl3
5.11
5.08
5.06
5.03
4.44
4.41
4.38
4.37
4.34
4.31
4.27
4.25
4.22
3.38
3.36
3.35
3.34
3.31
3.30
3.29
3.27
1.27
1.26
1.14
1.11
1.07
1.04
0.95
0.93
0.91
0.88
0.84
2.07
2.02
2.19
2.06
0.32
0.35
1.83
1.04
0.36
0.36
1.17
2.02
12.49
0.99
5.97
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5
Chemical shift (ppm)

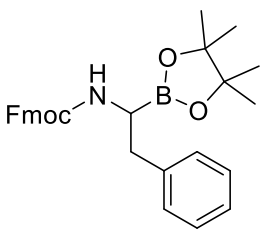

Fmoc
H
N
O
B
O
3e
157.1
156.9
144.3
144.2
141.4
127.7
127.1
125.3
120.0
84.2
77.2 CDCl3
66.7
47.5
37.4
27.0
27.0
25.1
24.9
16.8
16.7
12.3
12.1
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
N
O
B
O
(±)-3f
7.77
7.75
7.69
7.66
7.64
7.62
7.42
7.37
7.33
7.32
7.31
7.28
7.26 CDCl3
4.66
4.64
4.63
4.60
4.34
4.32
4.29
4.22
4.20
4.10
4.08
4.07
4.04
3.59
3.52
3.49
3.46
3.41
3.38
3.36
3.16
3.13
3.12
3.10
2.07
2.03
1.96
1.89
1.82
1.75
1.28
1.25
1.18
1.94
1.88
2.08
1.97
3.07
2.01
0.42
0.66
4.08
12.37
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

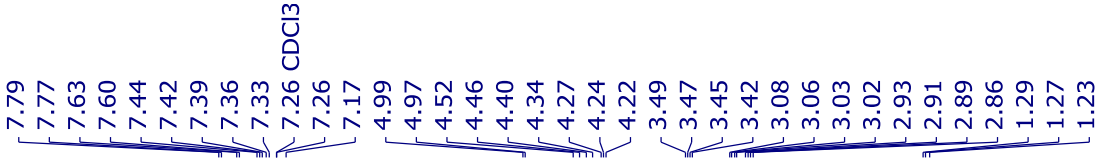

Fmoc
N
O
B
O
(±)-3f
155.2
154.9
144.4
144.4
141.4
141.4
127.8
127.7
127.2
127.1
125.6
125.5
120.0
83.9
83.8
77.2 CDCl3
67.4
67.3
47.7
47.5
47.3
46.2
29.1
28.1
27.2
25.8
25.0
25.0
24.7
24.6
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

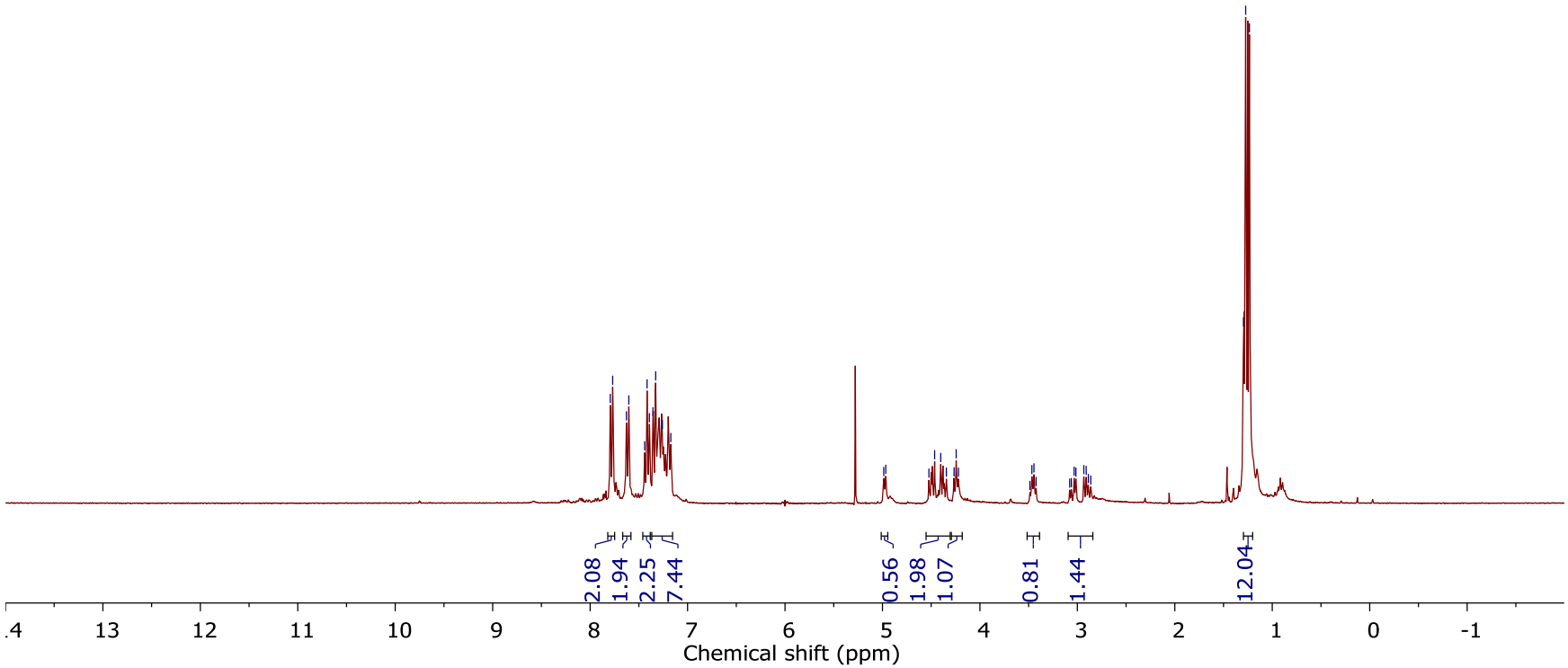

Fmoc
H
N
O
B
O
S
(±)-3g
7.77
7.75
7.62
7.62
7.60
7.59
7.42
7.40
7.37
7.34
7.31
7.29
7.26 CDCl3
5.11
5.09
4.46
4.43
4.40
4.34
4.31
4.25
4.23
4.21
3.34
3.32
3.30
3.28
2.56
2.54
2.52
2.49
2.08
2.04
2.03
2.00
1.98
1.27
2.06
1.97
2.09
2.03
0.61
1.98
1.06
0.72
1.80
2.57
1.18
1.06
12.45
Chemical shift (ppm)

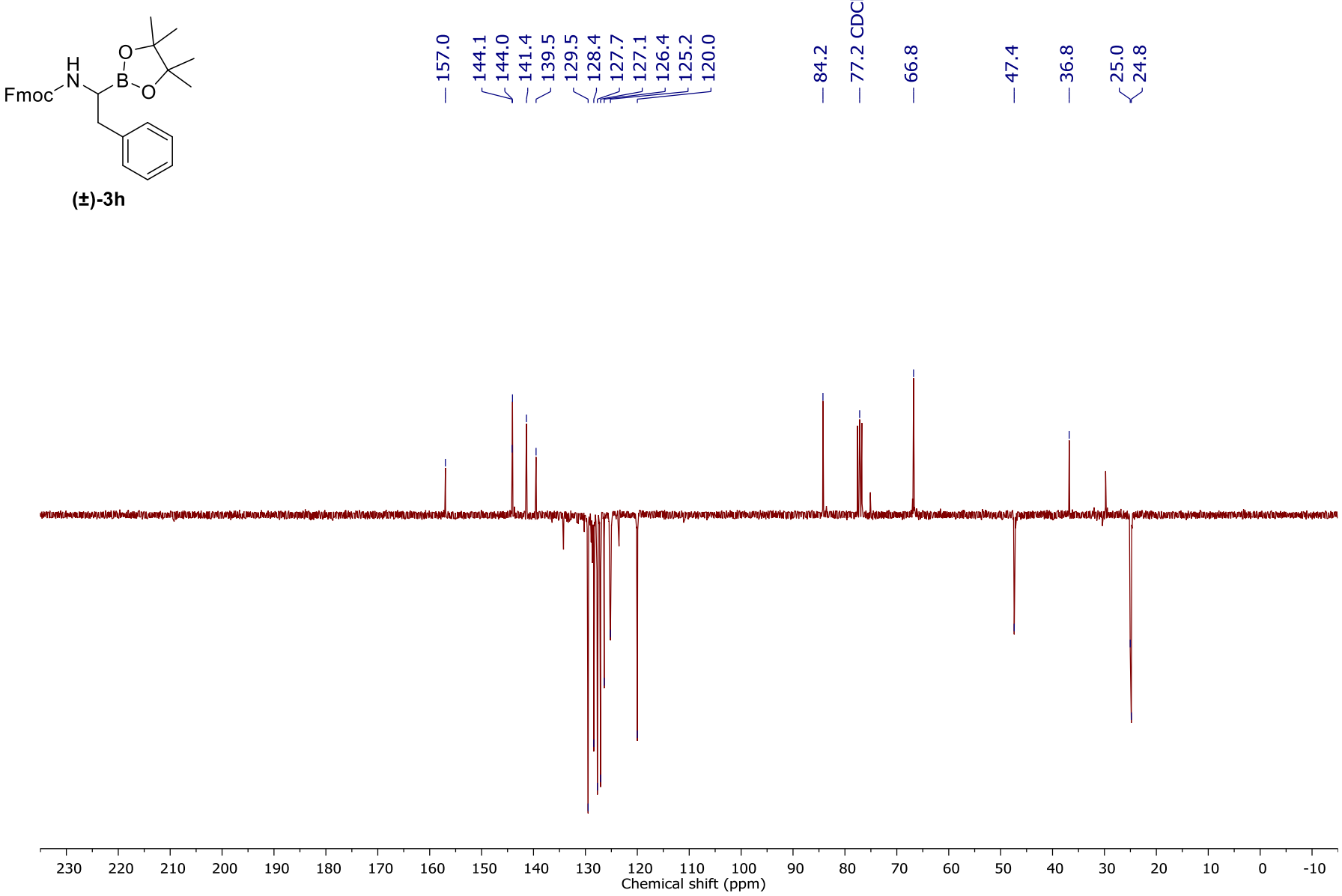

Fmoc
H
N
O
B
O
S
(±)-3g
157.0
144.3
144.1
141.5
127.8
127.2
125.3
120.1
84.4
77.2 CDCl3
66.8
47.5
31.5
30.2
25.0
24.9
15.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

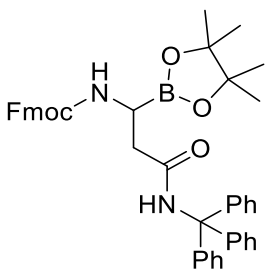

Fmoc
H
N
O
B
O

(±)-3h


7.79
7.77
7.63
7.60
7.44
7.42
7.39
7.36
7.33
7.26 CDCl3
7.26
7.17
4.99
4.97
4.52
4.46
4.40
4.34
4.27
4.24
4.22
3.49
3.47
3.45
3.42
3.08
3.06
3.03
3.02
2.93
2.91
2.89
2.86
1.29
1.27
1.23

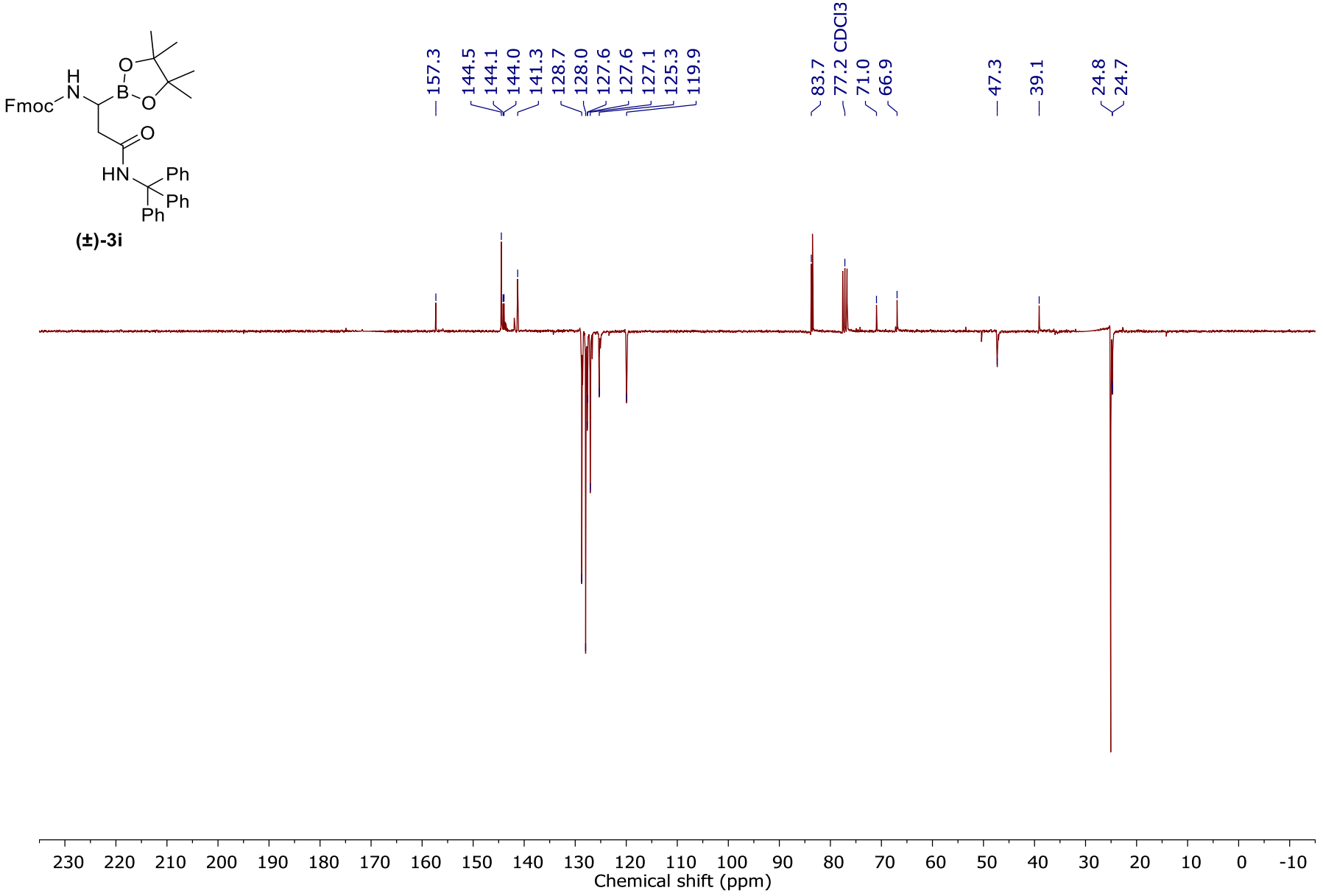

2.08
1.94
2.25
7.44
0.56
1.98
1.07
0.81
1.44
12.04
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

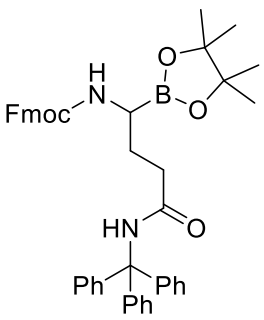

Fmoc
H
N
O
B
O
(±)-3h
157.0
144.1
144.0
141.4
139.5
129.5
128.4
127.7
127.1
126.4
125.2
120.0
84.2
77.2 CDCl3
66.8
47.4
36.8
25.0
24.8
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O
HN
Ph
Ph
Ph

(±)-3i

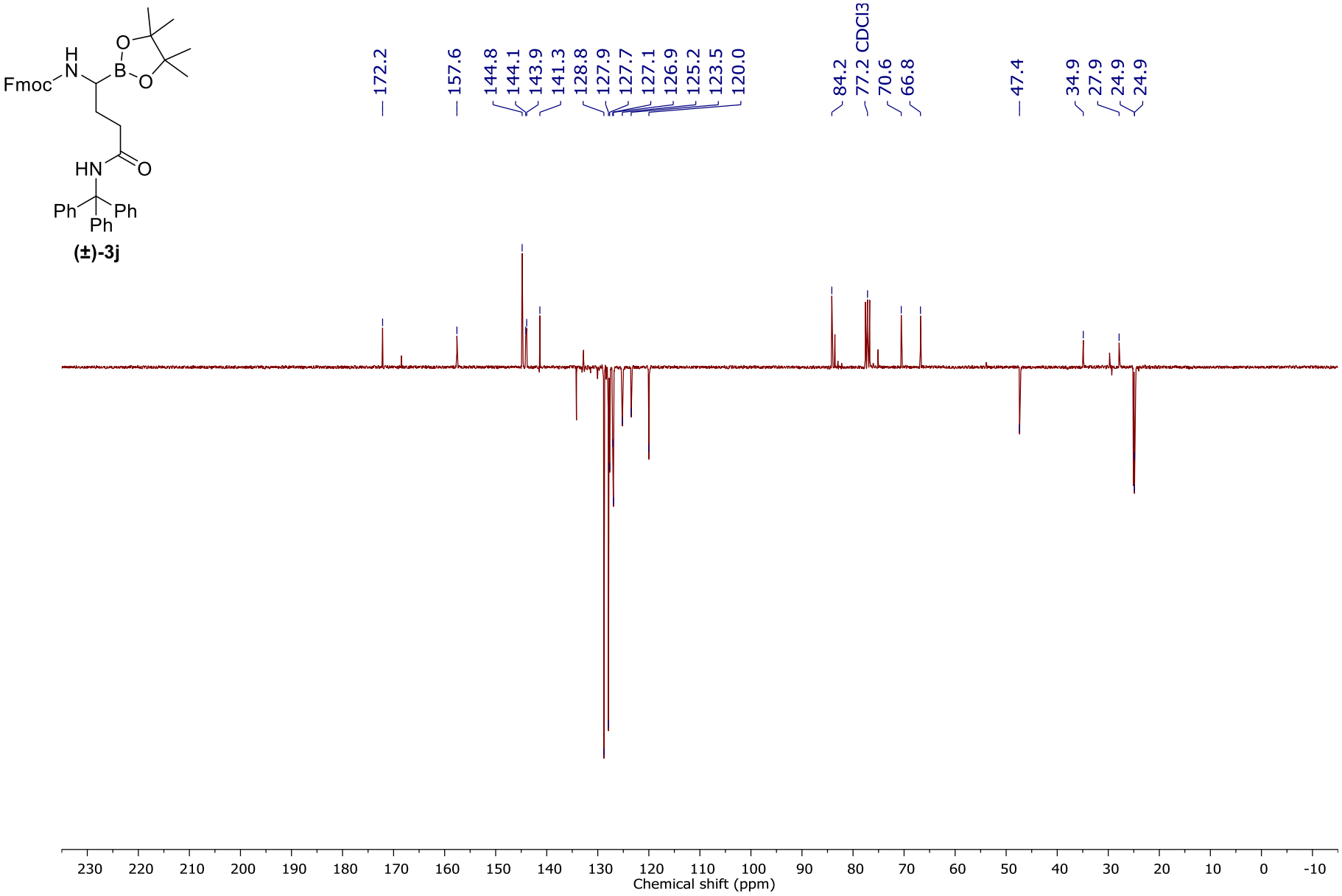
7.78
7.76
7.73
7.64
7.61
7.54
7.43
7.41
7.39
7.36
7.32
7.30
7.28
7.26 CDCl3
7.24
7.17
7.15
6.63
5.54
5.52
4.43
4.37
4.35
4.31
4.27
4.24
4.21
4.19
3.36
3.33
3.30
2.84
2.79
2.78
2.75
2.69
1.27
2.12
2.46
2.46
20.13
0.38
0.54
1.87
1.15
0.64
1.65
12.29
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

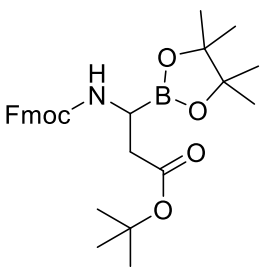

Fmoc
H
N
O
B
O
O
HN
Ph
Ph
Ph
(±)-3i
157.3
144.5
144.1
144.0
141.3
128.7
128.0
127.6
127.6
127.1
125.3
119.9
83.7
77.2 CDCl3
71.0
66.9
47.3
39.1
24.8
24.7
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
HN
O
Ph
Ph
Ph

(±)-3j

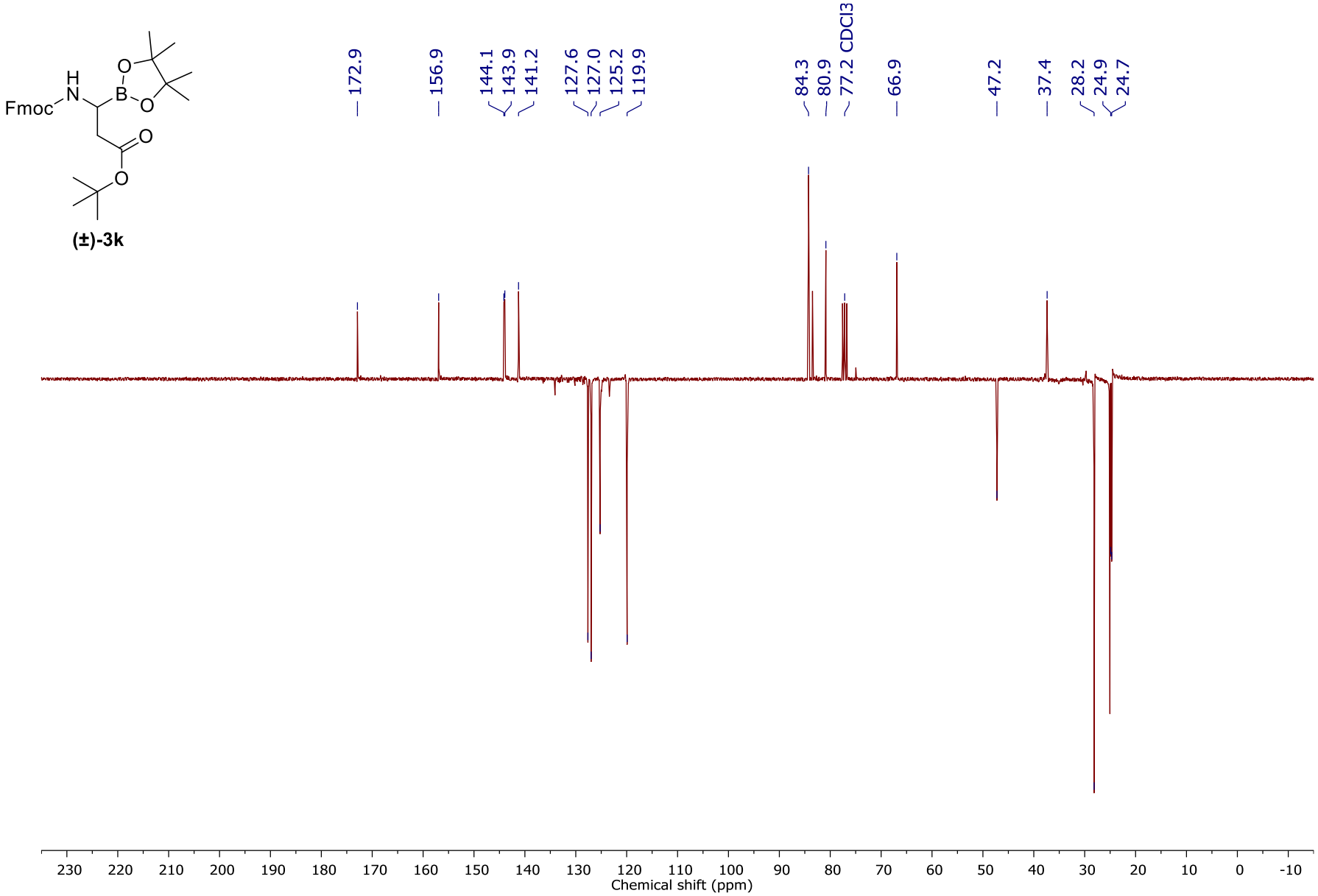
7.78
7.76
7.65
7.62
7.46
7.41
7.38
7.34
7.29
7.28
7.26
7.24
7.12
5.26
5.24
4.49
4.46
4.40
4.37
4.28
4.26
4.23
3.26
3.24
3.21
3.19
2.45
2.40
2.38
2.33
2.07
2.00
1.91
1.89
1.84
1.28
1.26
2.31
2.06
2.42
17.00
0.76
0.71
1.81
1.01
0.83
1.67
1.76
12.46
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

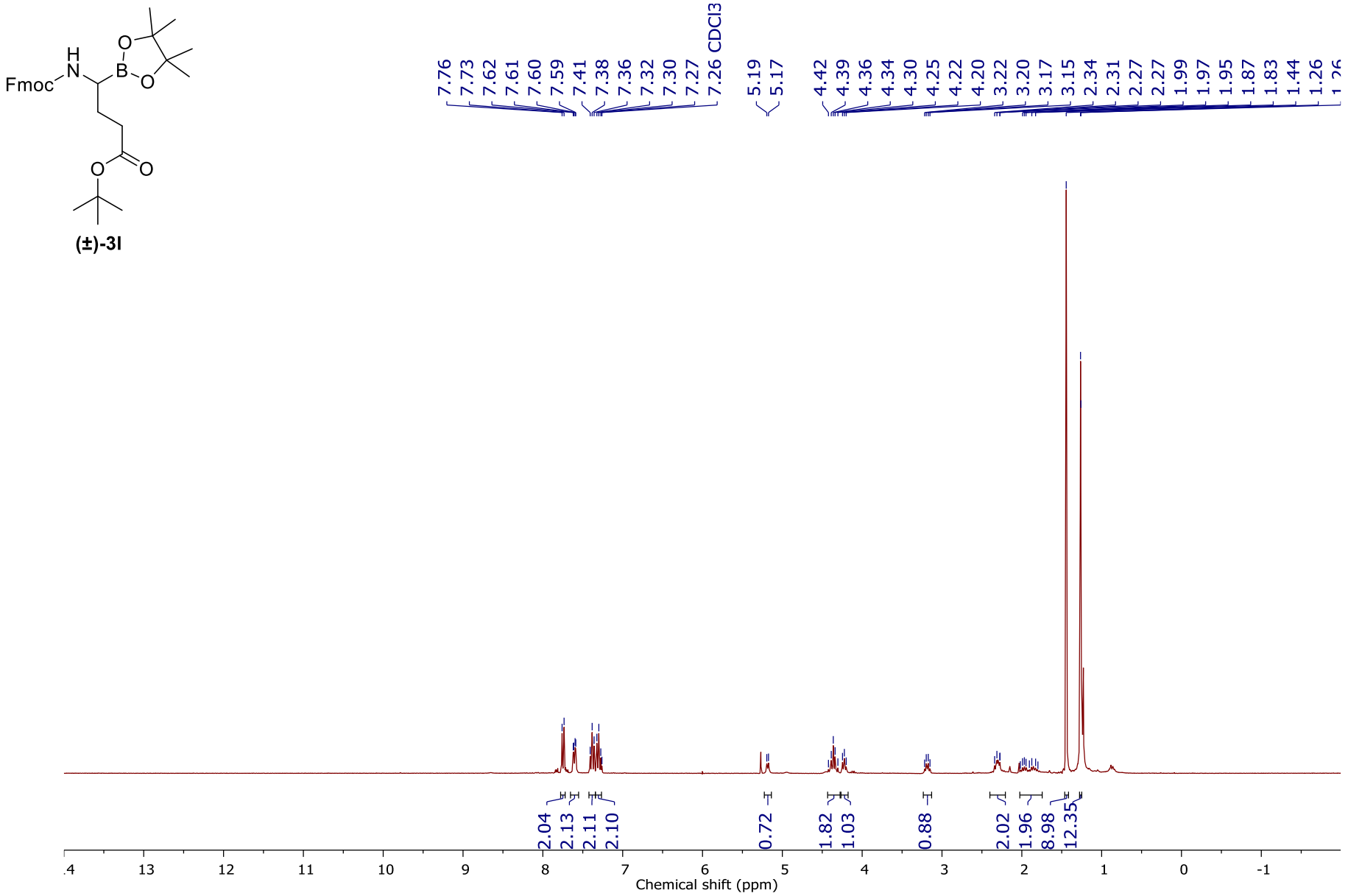

Fmoc
H
N
O
B
O
HN
O
Ph
Ph
Ph
(±)-3j
172.2
157.6
144.8
144.1
143.9
141.3
128.8
127.9
127.7
127.1
126.9
125.2
123.5
120.0
84.2
77.2 CDCl3
70.6
66.8
47.4
34.9
27.9
24.9
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

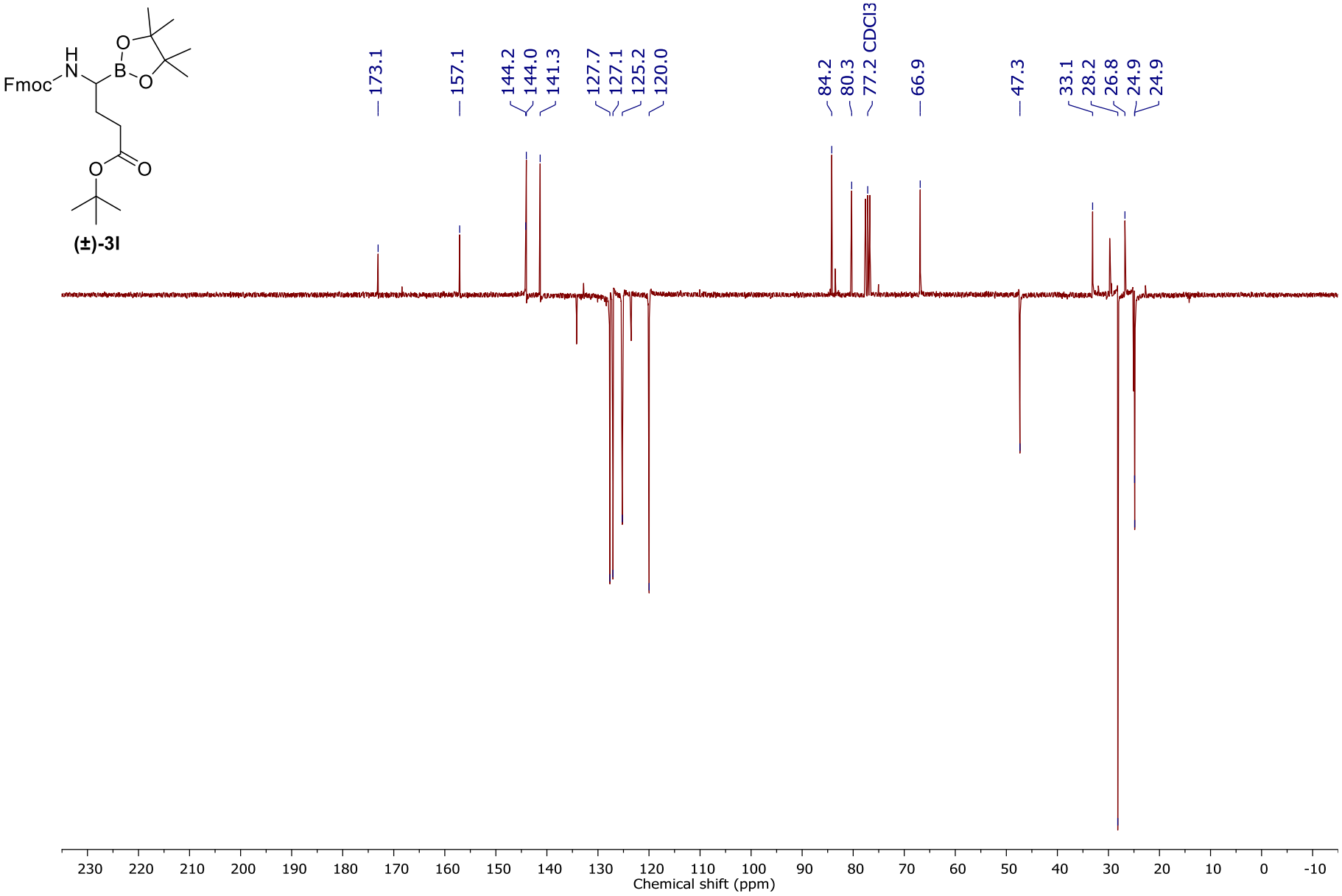

Fmoc
H
N
O
B
O
O
O
O

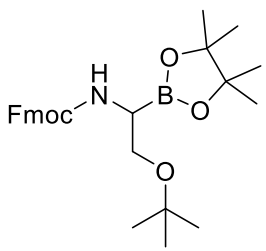
(±)-3k

7.75
7.72
7.61
7.59
7.57
7.40
7.37
7.35
7.31
7.28
7.26 CDCl3
7.26
5.54
5.52
4.39
4.37
4.33
4.31
4.27
4.24
4.21
4.19
3.42
3.40
3.38
3.36
2.76
2.74
2.70
2.69
2.63
2.62
2.57
2.56
1.45
1.29
1.26
2.00
2.01
2.06
1.87
0.70
1.67
0.97
0.77
1.69
8.62
12.30
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O
O
O
(±)-3k
172.9
156.9
144.1
143.9
141.2
127.6
127.0
125.2
119.9
84.3
80.9
77.2 CDCl3
66.9
47.2
37.4
28.2
24.9
24.7
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
Chemical shift (ppm)

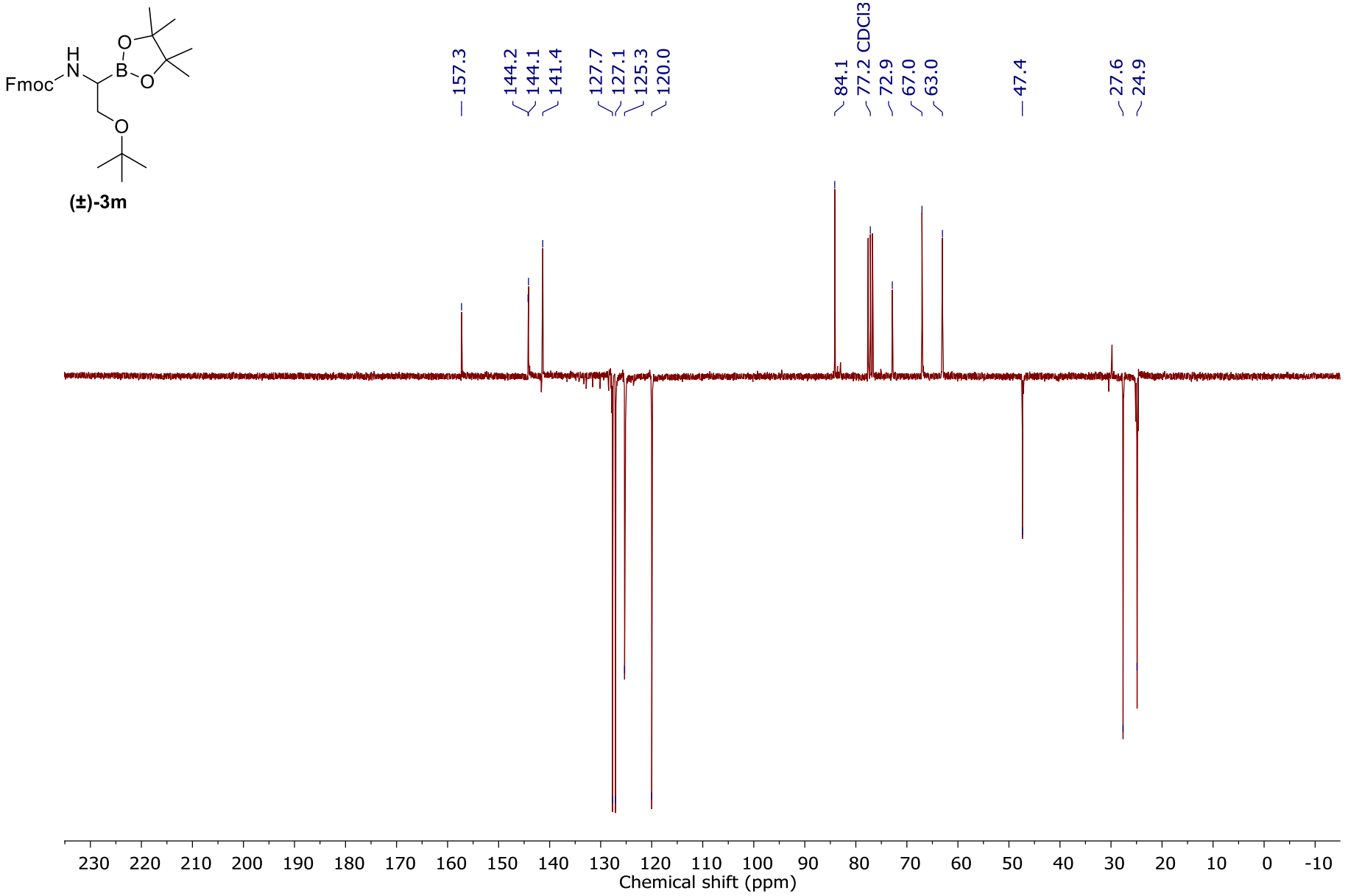

Fmoc
H
N
O
B
O
O
O
(±)-3l
7.76
7.73
7.62
7.61
7.60
7.59
7.41
7.38
7.36
7.32
7.30
7.27
7.26 CDCl3
5.19
5.17
4.42
4.39
4.36
4.34
4.30
4.25
4.22
4.20
3.22
3.20
3.17
3.15
2.34
2.31
2.27
2.27
1.99
1.97
1.95
1.87
1.83
1.44
1.26
2.04
2.13
2.11
2.10
0.72
1.82
1.03
0.88
2.02
1.96
8.98
12.35
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

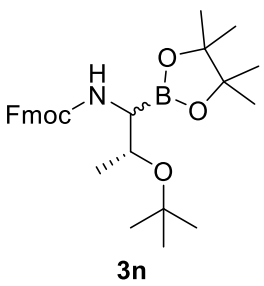

Fmoc
H
N
O
B
O
O
O
O
(±)-3l
173.1
157.1
144.2
144.0
141.3
127.7
127.1
125.2
120.0
84.2
80.3
77.2 CDCl3
66.9
47.3
33.1
28.2
26.8
24.9
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O

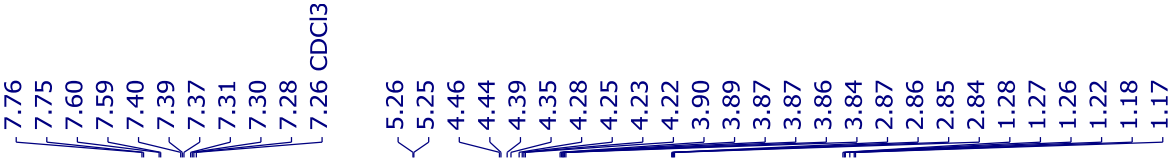
(±)-3m

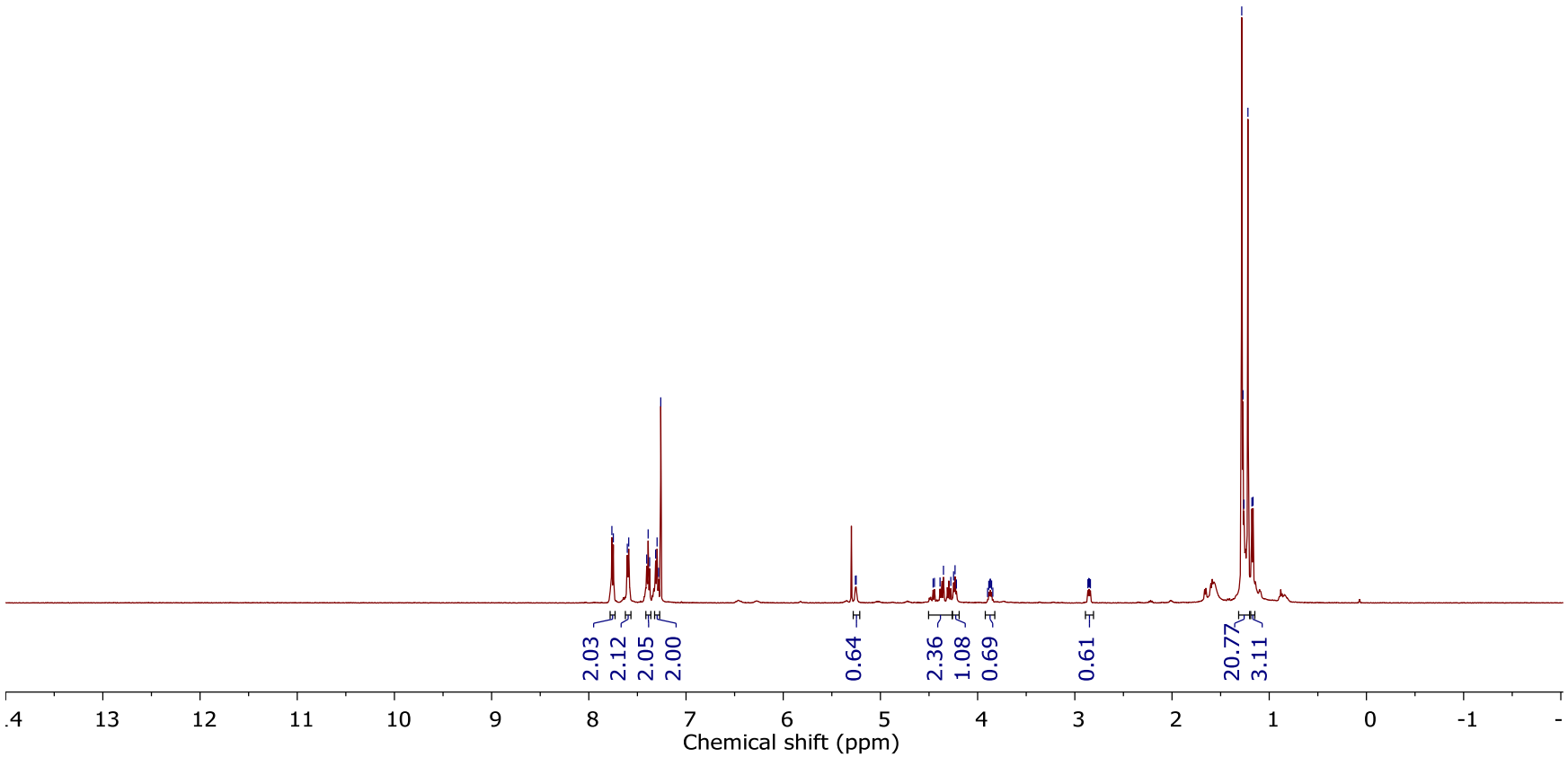
7.77
7.75
7.65
7.63
7.62
7.61
7.42
7.40
7.37
7.34
7.31
7.29
7.26 CDCl3
5.44
5.42
4.44
4.38
4.33
4.30
4.27
4.25
4.22
3.57
3.56
3.38
3.36
3.34
3.33
1.29
1.17
2.05
2.08
2.09
2.11
0.66
1.81
1.07
1.49
0.93
12.19
8.65
Chemical shift (ppm)

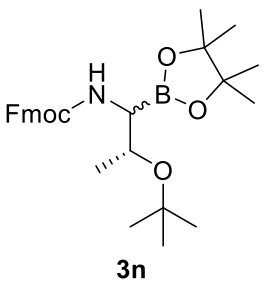

Fmoc
H
N
O
B
O
O
(±)-3m
157.3
144.2
144.1
141.4
127.7
127.1
125.3
120.0
84.1
77.2 CDCl3
72.9
67.0
63.0
47.4
27.6
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O

3n

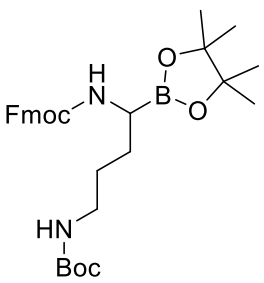

7.76
7.75
7.60
7.59
7.40
7.39
7.37
7.31
7.30
7.28
7.26 CDCl3
5.26
5.25
4.46
4.44
4.39
4.35
4.28
4.25
4.23
4.22
3.90
3.89
3.87
3.87
3.86
3.84
2.87
2.86
2.85
2.84
1.28
1.27
1.26
1.22
1.18
1.17


2.03
2.12
2.05
2.00
0.64
2.36
1.08
0.69
0.61
20.77
3.11
.4
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O

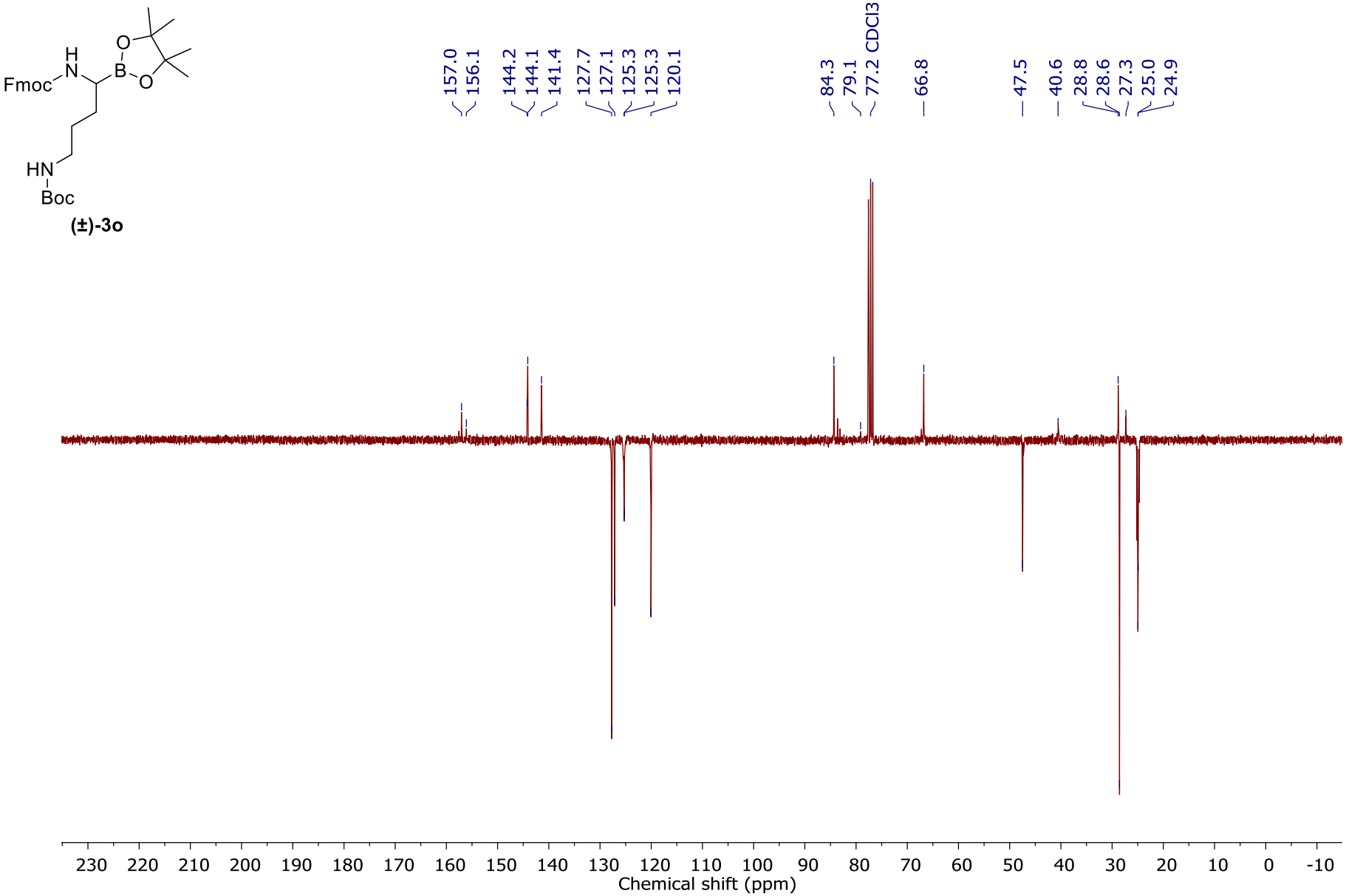
3n

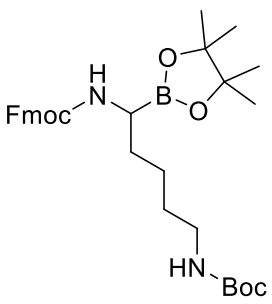
157.5
144.2
141.4
127.7
127.1
125.4
125.3
120.1
83.9
77.2 CDCl3
73.9
68.0
67.3
47.4
29.0
25.2
25.0
21.4
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
HN
Boc

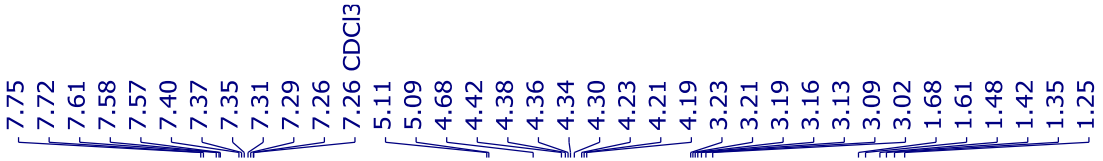
(±)-3o

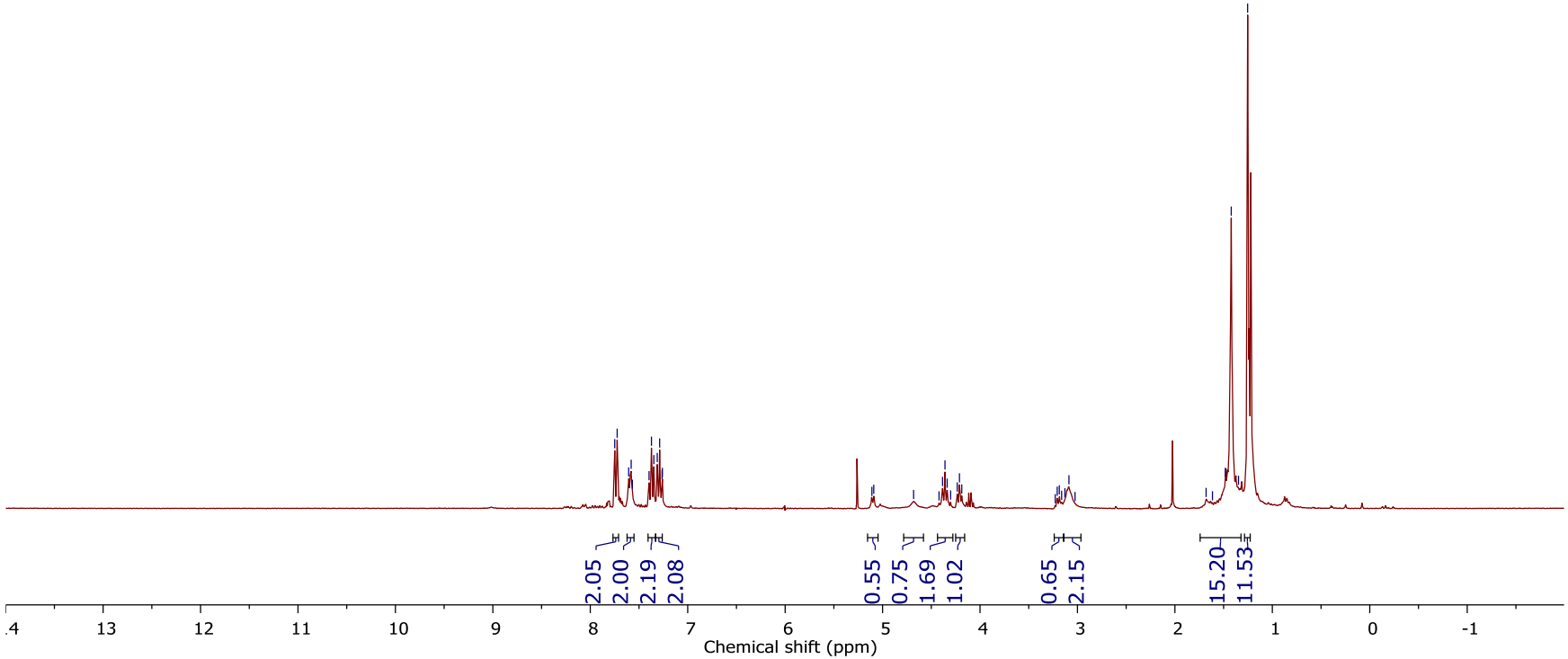
7.77
7.75
7.62
7.60
7.42
7.39
7.37
7.33
7.31
7.29
7.26 CDCl3
5.06
5.04
4.63
4.45
4.42
4.39
4.34
4.31
4.25
4.22
4.20
3.22
3.19
3.13
3.11
3.02
1.71
1.67
1.57
1.51
1.44
1.26
1.26
2.02
2.18
2.18
2.21
0.63
0.63
2.17
1.22
3.45
4.03
8.82
12.94
Chemical shift (ppm)

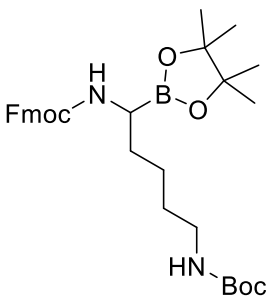

Fmoc
H
N
O
B
O
HN
Boc
(±)-3o
157.0
156.1
144.2
144.1
141.4
127.7
127.1
125.3
125.3
120.1
84.3
79.1
77.2 CDCl3
66.8
47.5
40.6
28.8
28.6
27.3
25.0
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
HN
Boc

(±)-3p


7.75
7.72
7.61
7.58
7.57
7.40
7.37
7.35
7.31
7.29
7.26
7.26 CDCl3
5.11
5.09
4.68
4.42
4.38
4.36
4.34
4.30
4.23
4.21
4.19
3.23
3.21
3.19
3.16
3.13
3.09
3.02
1.68
1.61
1.48
1.42
1.35
1.25


2.05
2.00
2.19
2.08
0.55
0.75
1.69
1.02
0.65
2.15
15.20
11.53
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

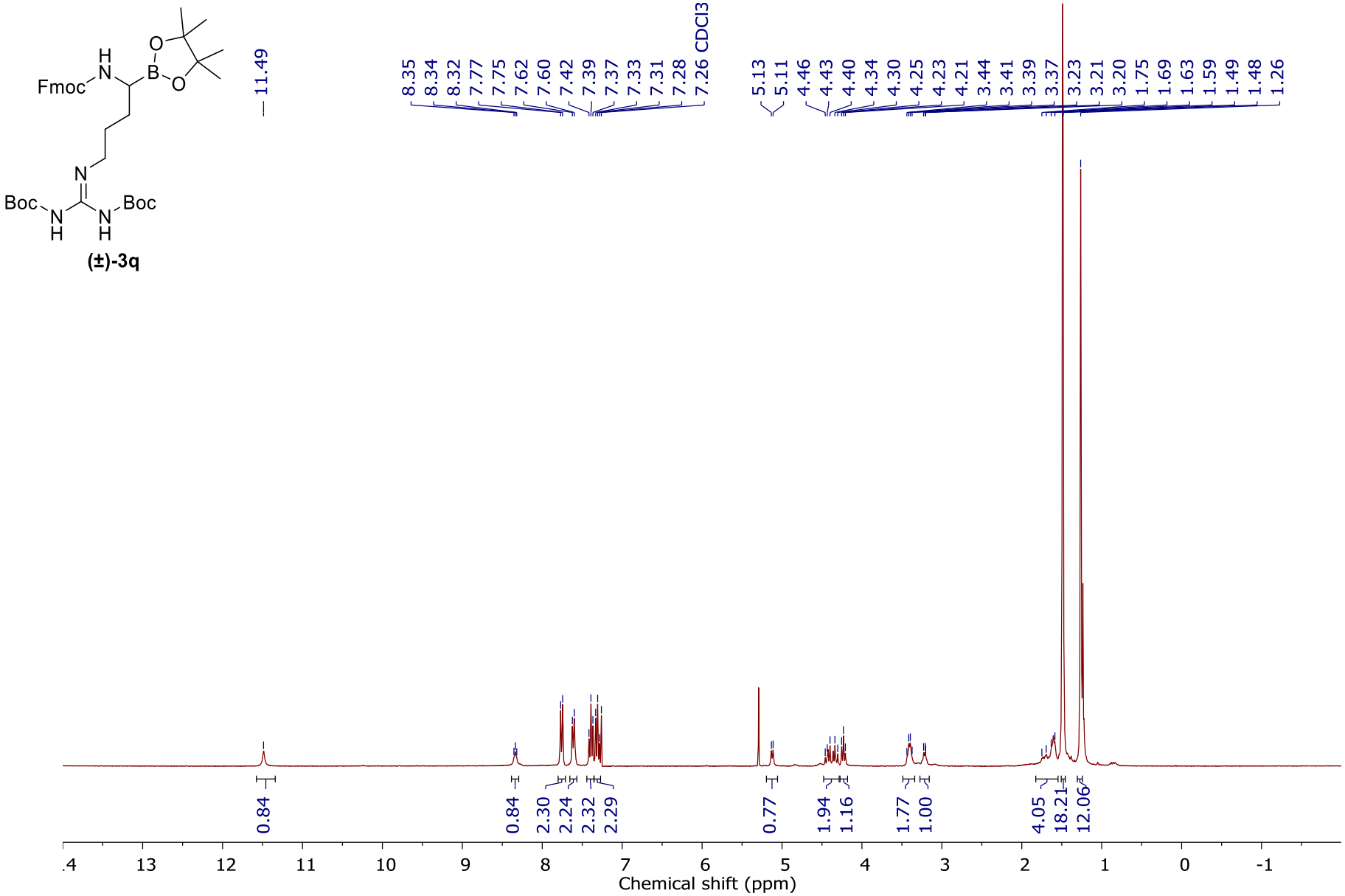


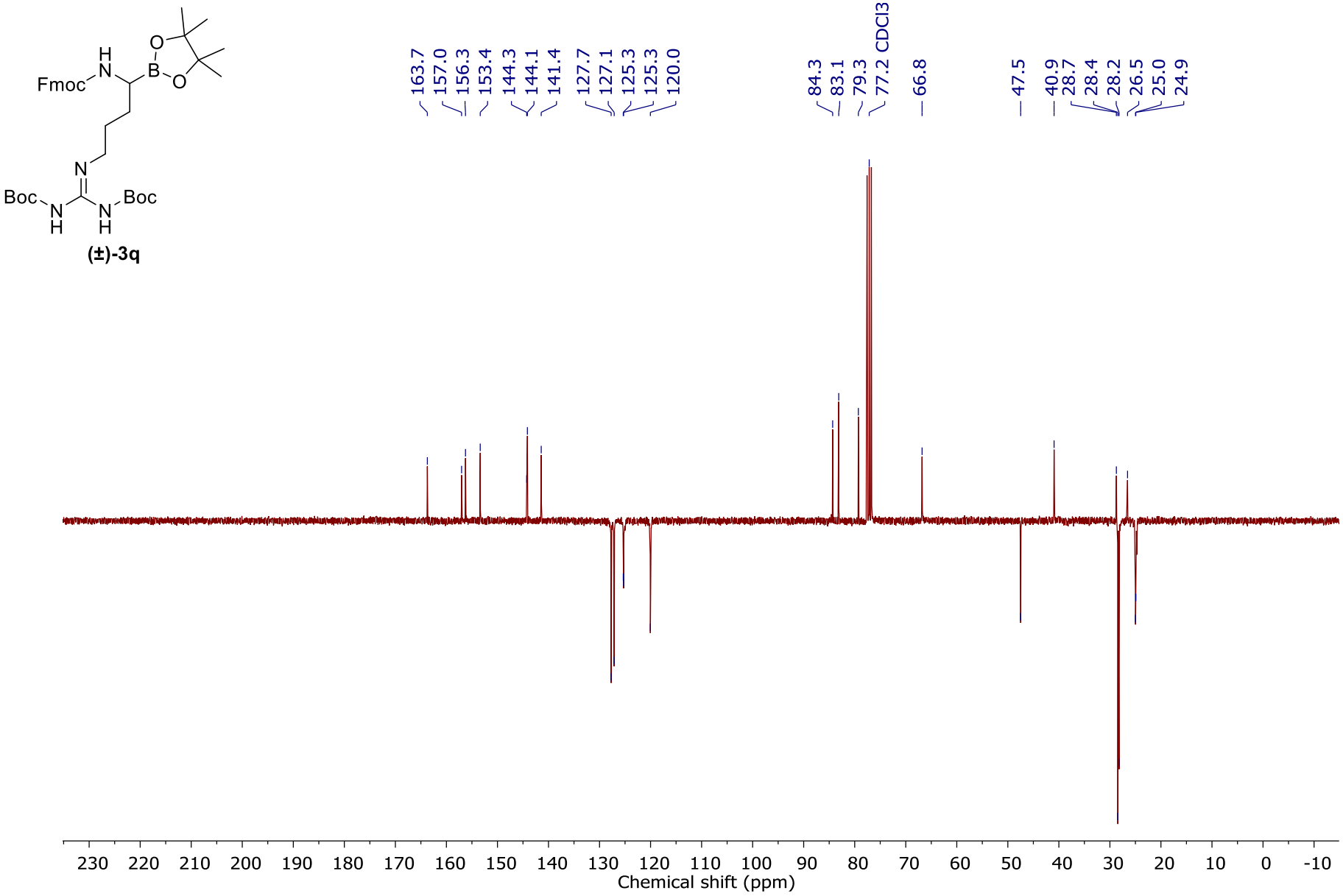
(±)-3p

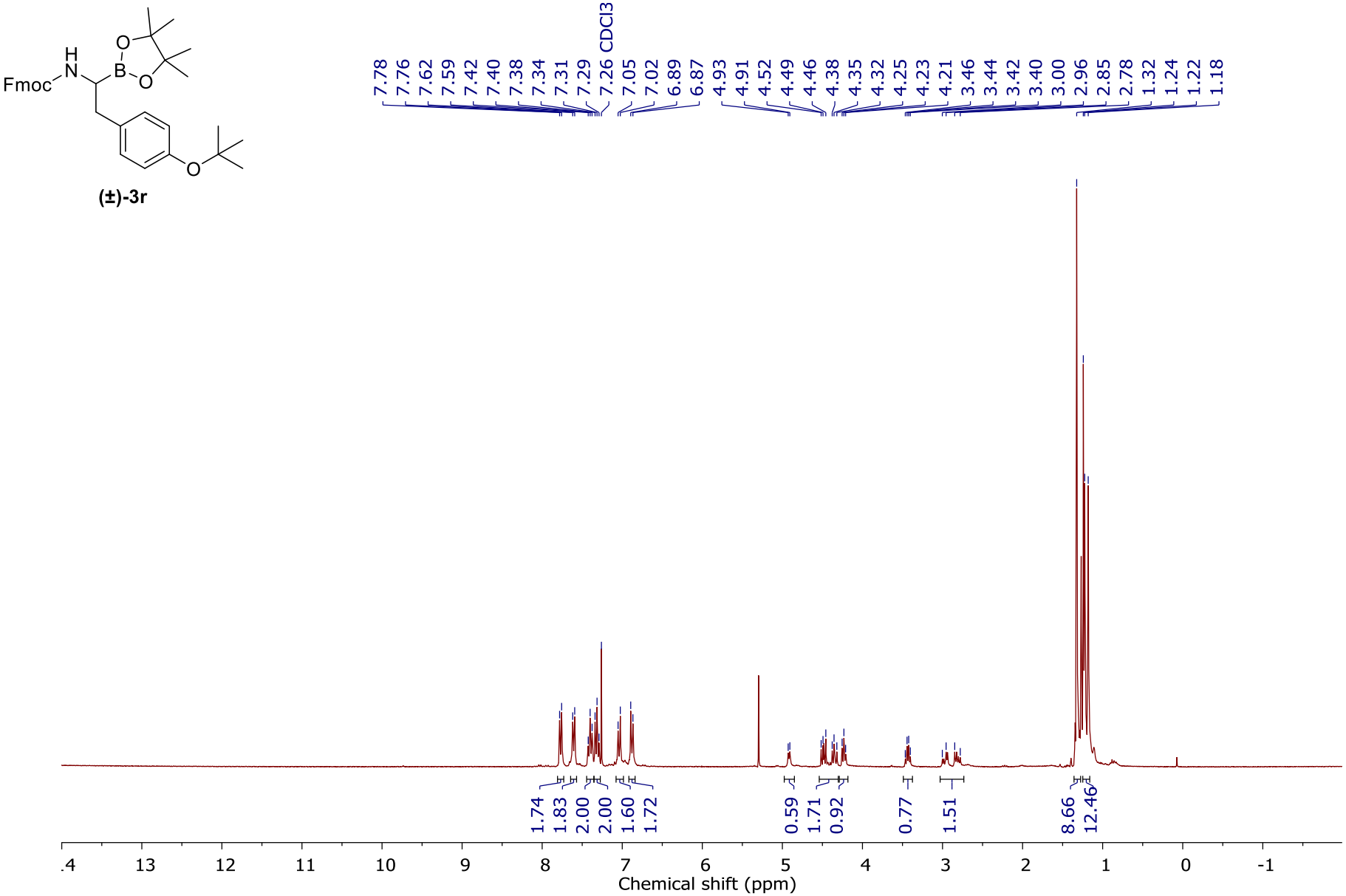
157.0
156.1
144.3
144.2
141.4
127.7
127.1
125.3
120.1
84.3
79.1
77.2 CDCl3
66.8
47.5
40.6
31.2
29.9
28.6
25.0
24.9
24.0

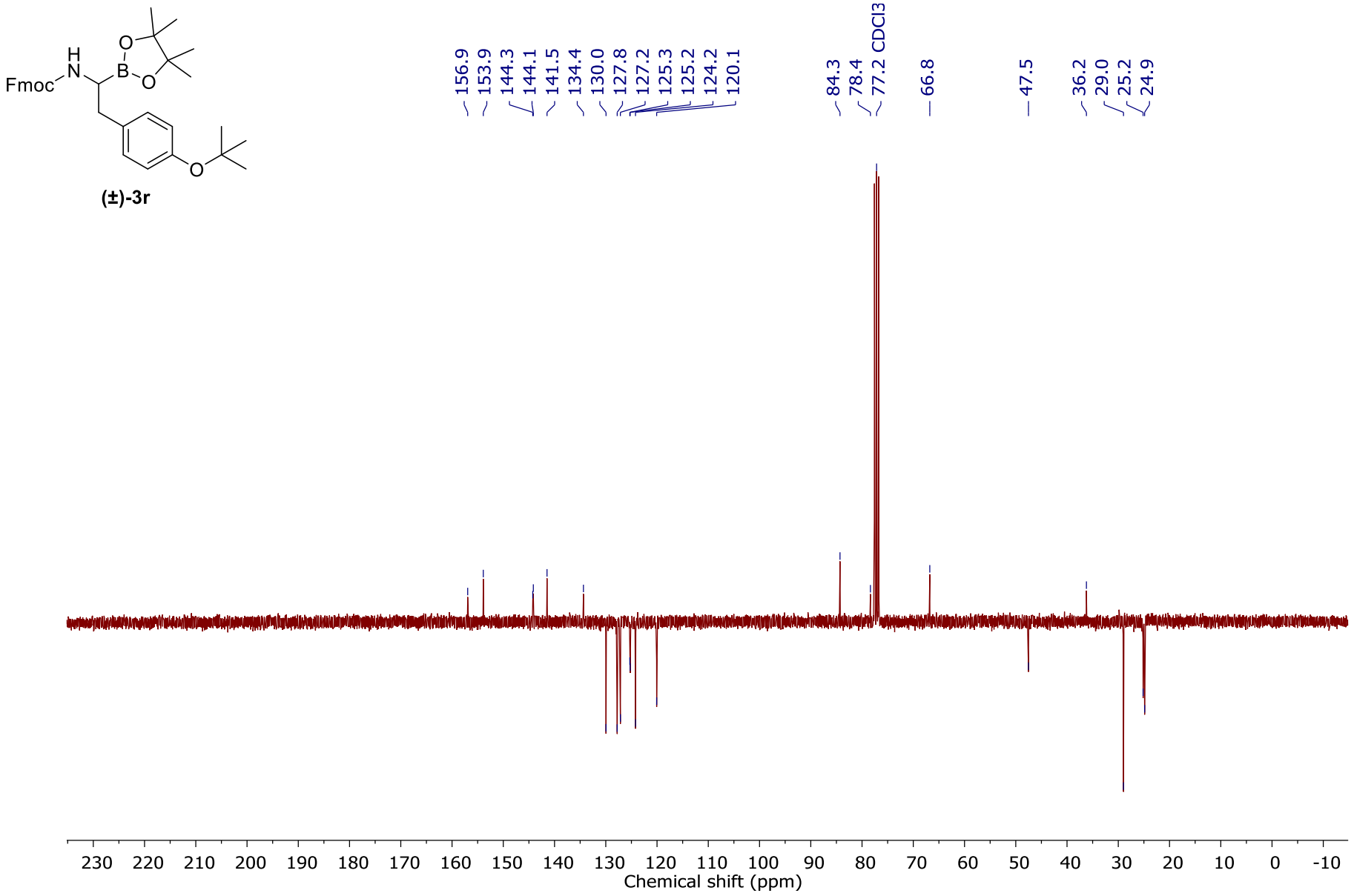
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10

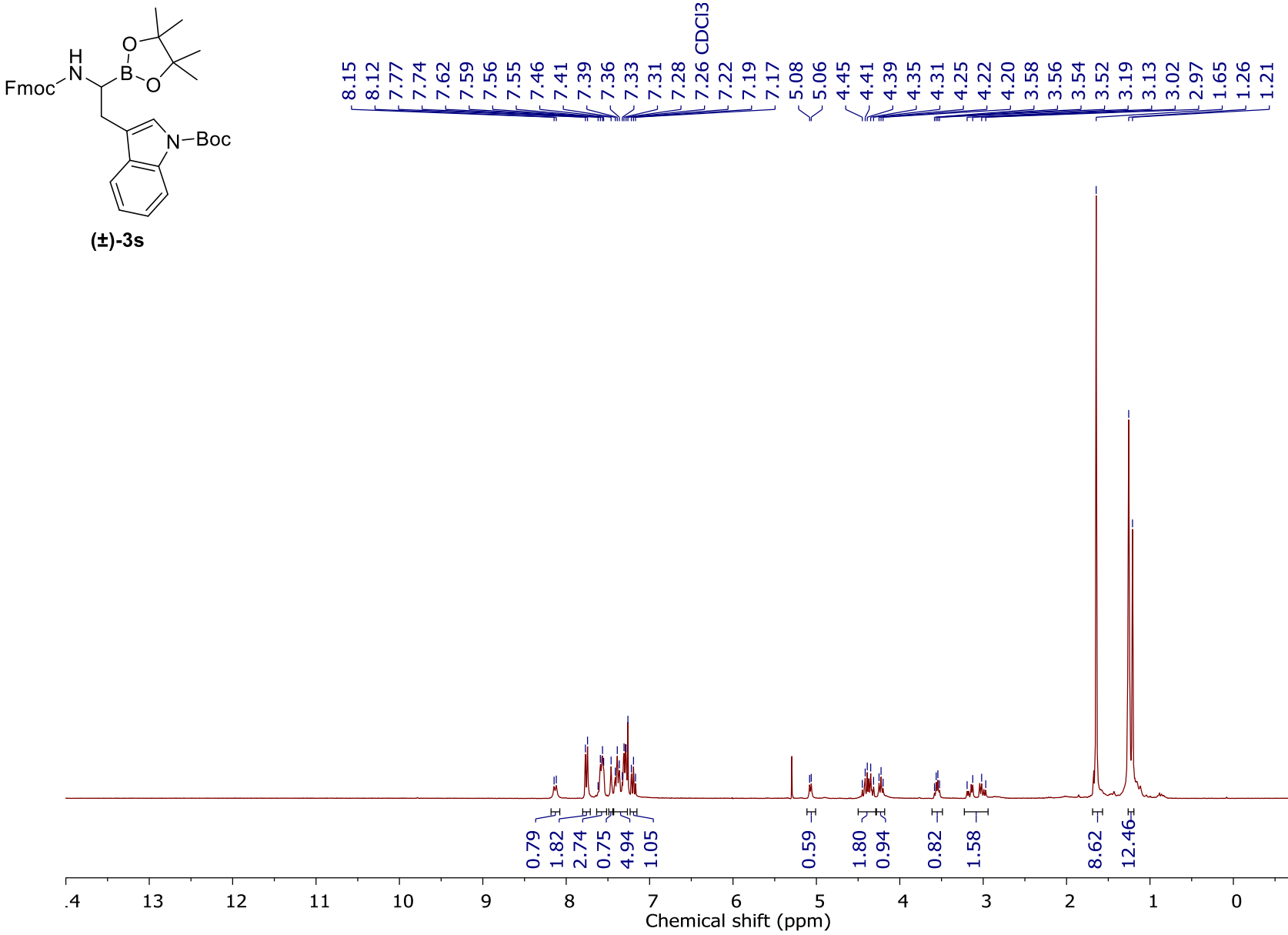
Chemical shift (ppm)

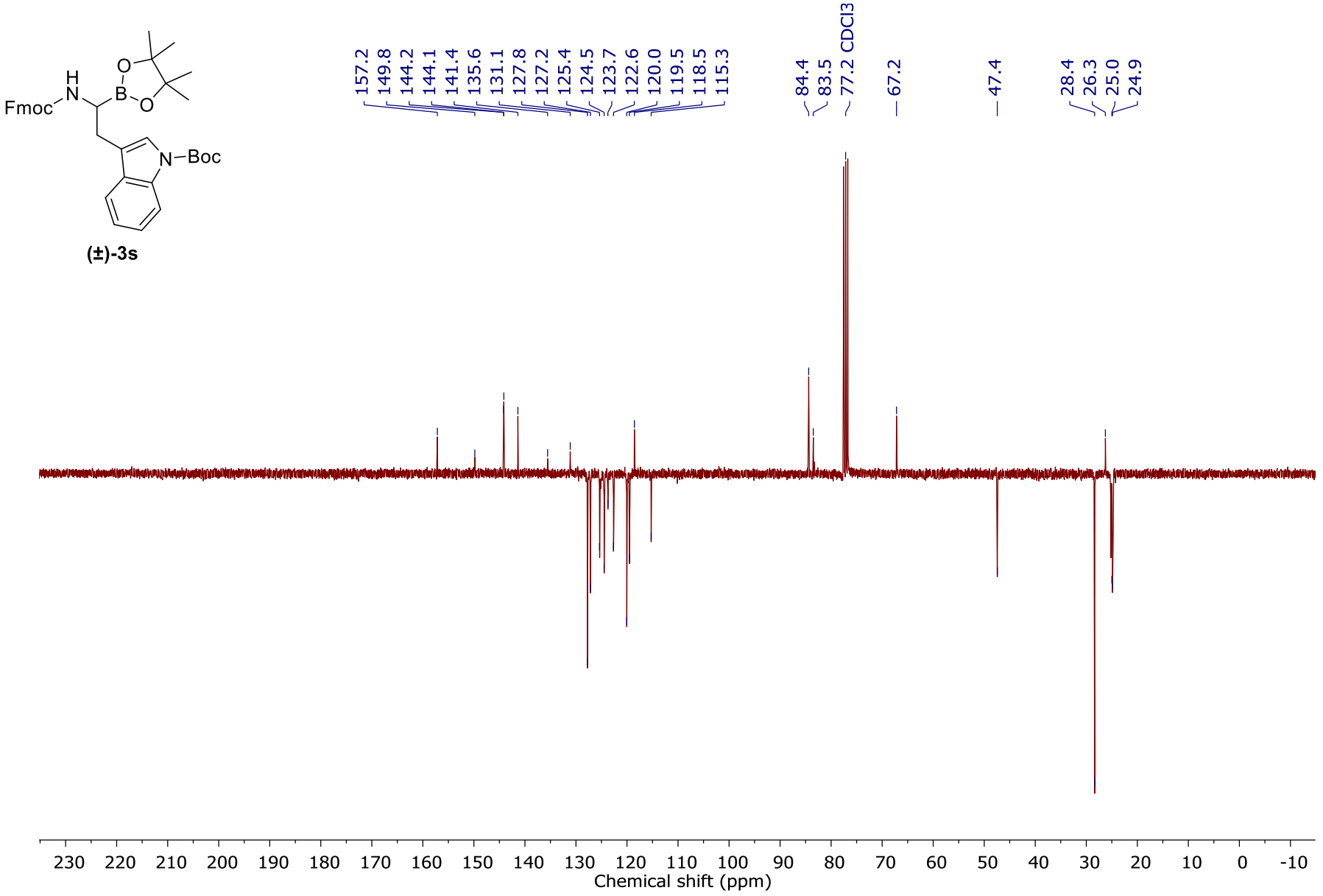

Fmoc
Boc
Boc
(±)-3q
11.49
8.35
8.34
8.32
7.77
7.75
7.62
7.60
7.42
7.39
7.37
7.33
7.31
7.28
7.26 CDCl3
5.13
5.11
4.46
4.43
4.40
4.34
4.30
4.25
4.23
4.21
3.44
3.41
3.39
3.37
3.23
3.21
3.20
1.75
1.69
1.63
1.59
1.49
1.48
1.26
0.84
0.84
2.30
2.24
2.32
2.29
0.77
1.94
1.16
1.77
1.00
4.05
18.21
12.06
Chemical shift (ppm)

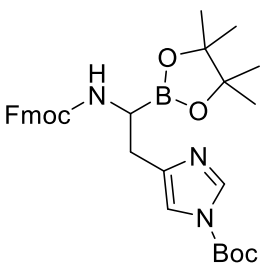

Fmoc
Boc
Boc
(±)-3q
163.7
157.0
156.3
153.4
144.3
144.1
141.4
127.7
127.1
125.3
125.3
120.0
84.3
83.1
79.3
77.2 CDCl3
66.8
47.5
40.9
28.7
28.4
28.2
26.5
25.0
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O
(±)-3r
7.78
7.76
7.62
7.59
7.42
7.40
7.38
7.34
7.31
7.29
7.26 CDCl3
7.05
7.02
6.89
6.87
4.93
4.91
4.52
4.49
4.46
4.38
4.35
4.32
4.25
4.23
4.21
3.46
3.44
3.42
3.40
3.00
2.96
2.85
2.78
1.32
1.24
1.22
1.18
1.74
1.83
2.00
2.00
1.60
1.72
0.59
1.71
0.92
0.77
1.51
8.66
12.46
Chemical shift (ppm)


Fmoc
H
N
O
B
O
O
(±)-3r
156.9
153.9
144.3
144.1
141.5
134.4
130.0
127.8
127.2
125.3
125.2
124.2
120.1
84.3
78.4
77.2 CDCl3
66.8
47.5
36.2
29.0
25.2
24.9
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
Chemical shift (ppm)

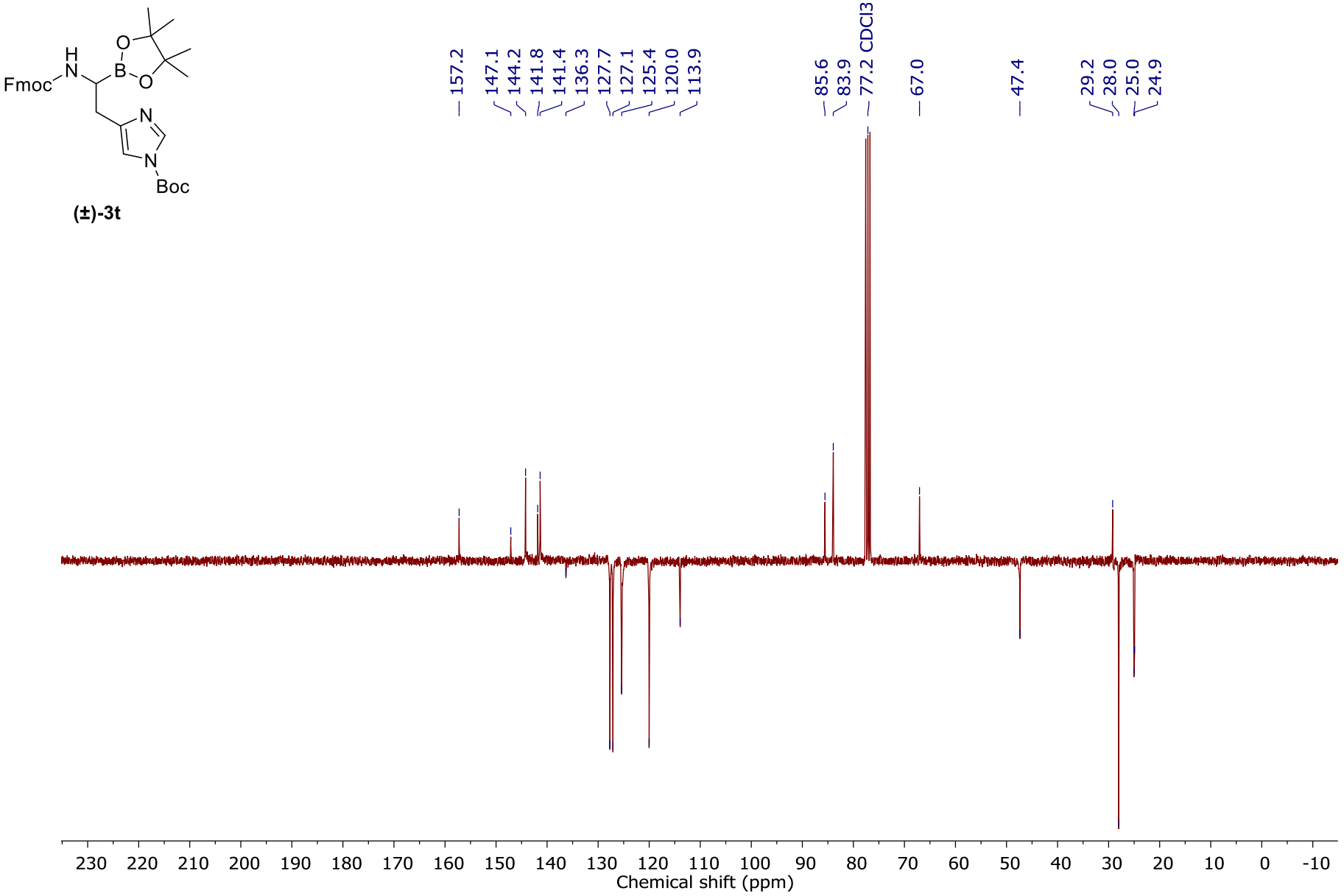

Fmoc
H
N
O
B
O
N–Boc
(±)-3s
8.15
8.12
7.77
7.74
7.62
7.59
7.56
7.55
7.46
7.41
7.39
7.36
7.33
7.31
7.28
7.26 CDCl3
7.22
7.19
7.17
5.08
5.06
4.45
4.41
4.39
4.35
4.31
4.25
4.22
4.20
3.58
3.56
3.54
3.52
3.19
3.13
3.02
2.97
1.65
1.26
1.21
0.79
1.82
2.74
0.75
4.94
1.05
0.59
1.80
0.94
0.82
1.58
8.62
12.46
Chemical shift (ppm)


Fmoc
H
N
O
B
O
N–Boc
(±)-3s
157.2
149.8
144.2
144.1
141.4
135.6
131.1
127.8
127.2
125.4
124.5
123.7
122.6
120.0
119.5
118.5
115.3
84.4
83.5
77.2 CDCl3
67.2
47.4
28.4
26.3
25.0
24.9
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
Chemical shift (ppm)

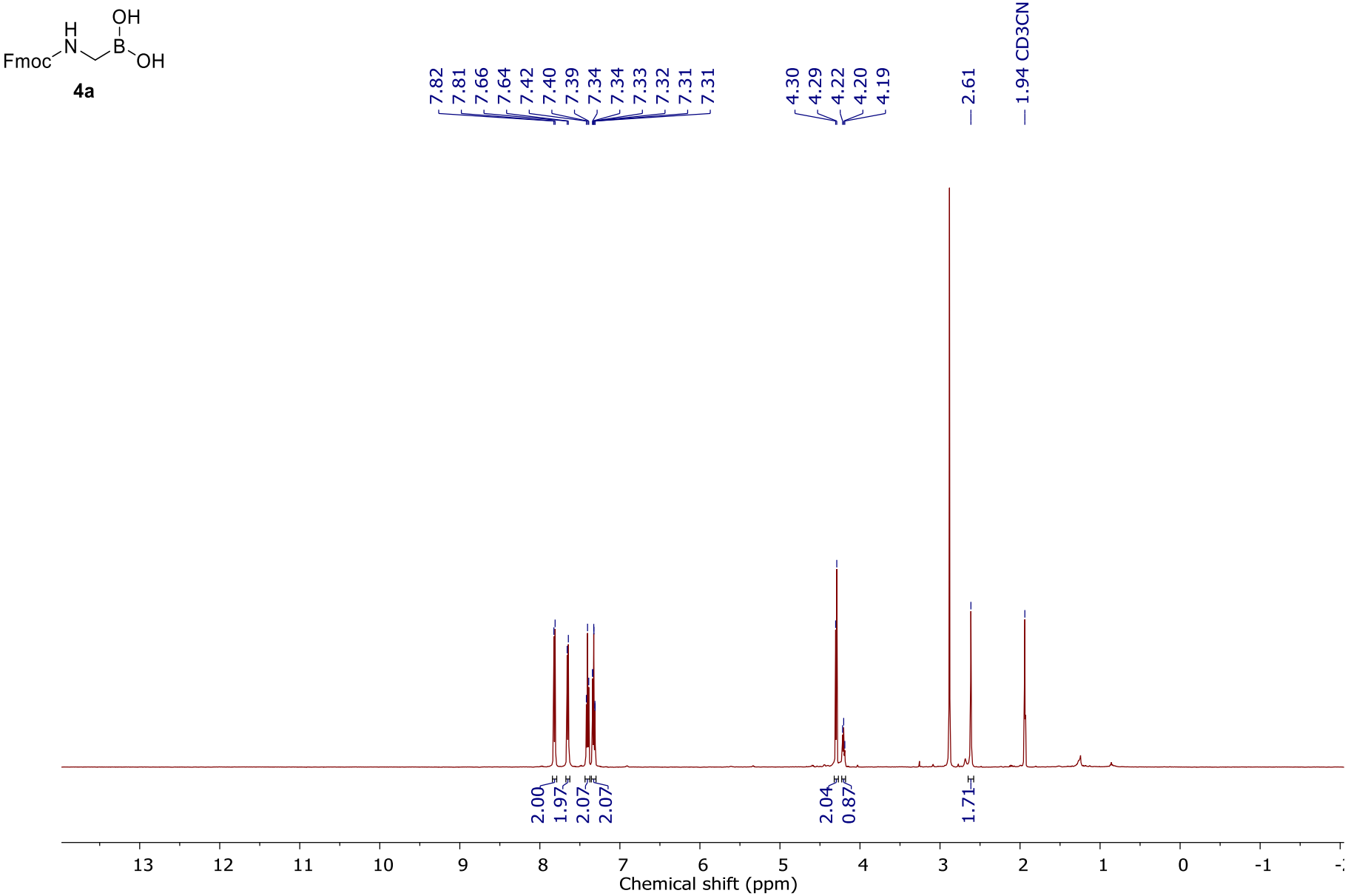

Fmoc
H
N
O
B
O
N
N
Boc

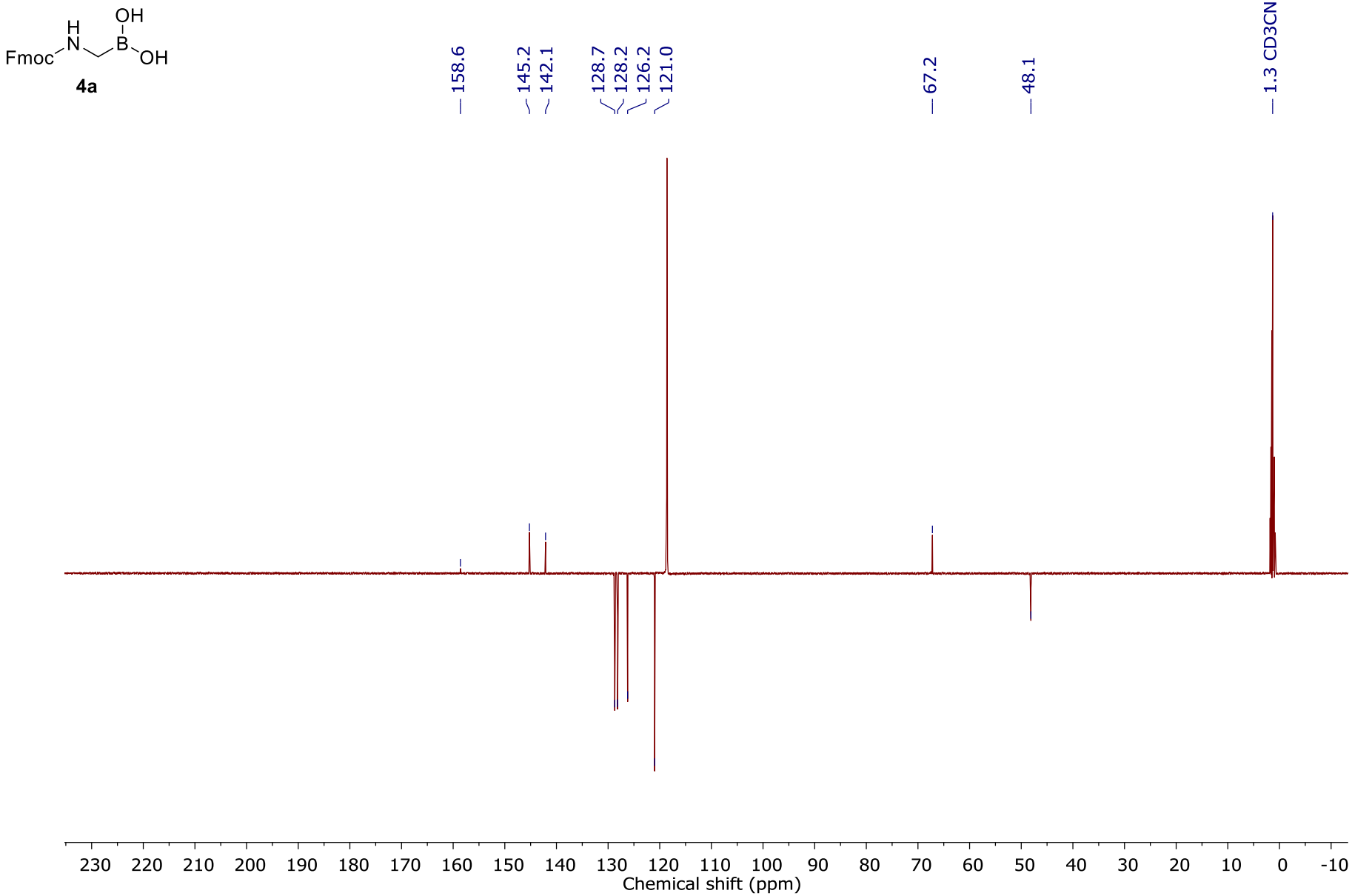
(±)-3t

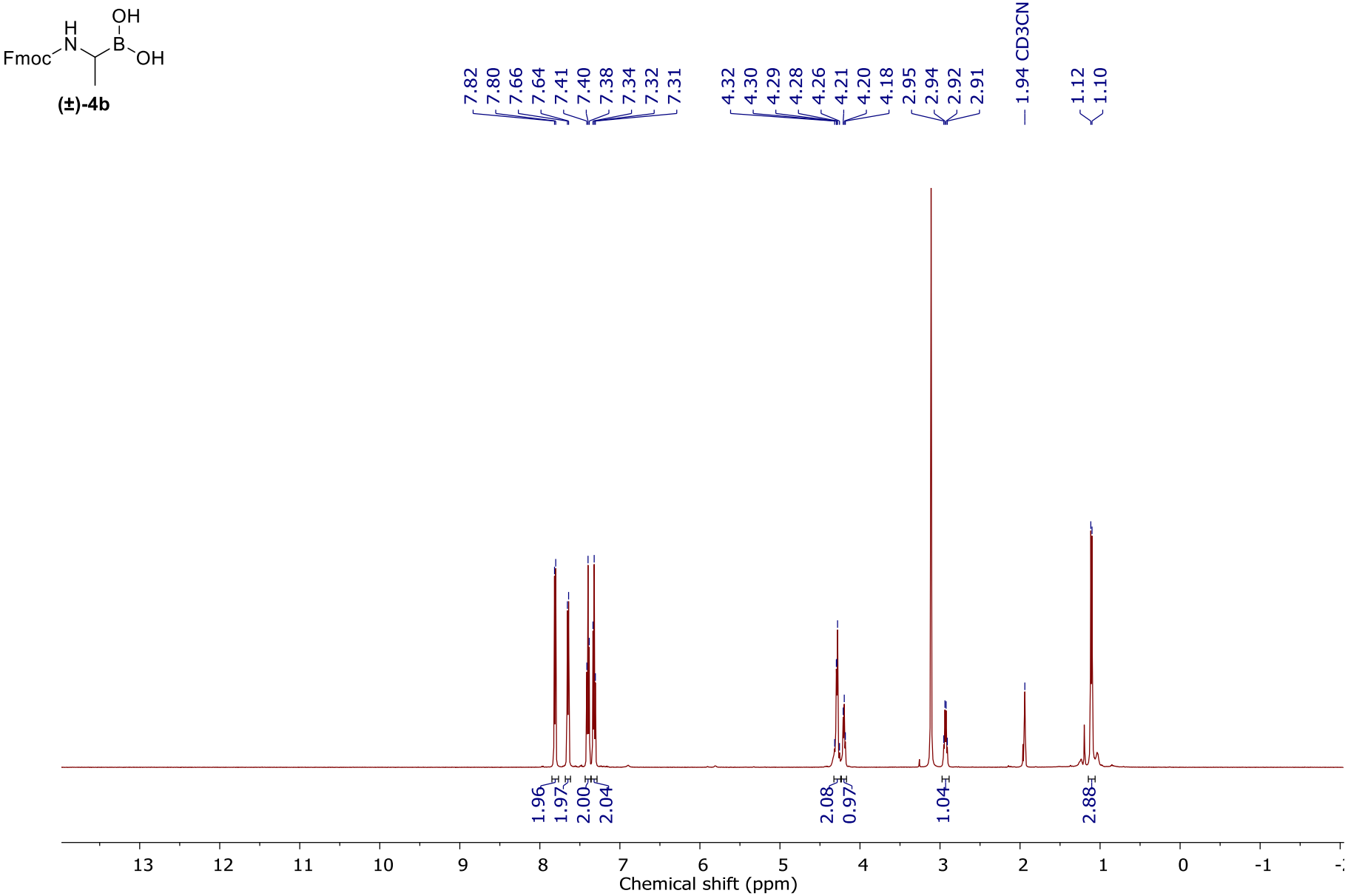
8.02
7.76
7.74
7.60
7.58
7.56
7.41
7.38
7.36
7.31
7.29
7.26
7.26 CDCl3
7.12
5.49
5.47
4.39
4.36
4.33
4.30
4.27
4.25
4.23
4.21
3.48
3.46
3.44
3.42
2.99
2.97
2.94
2.92
2.89
2.87
2.84
2.82
1.59
1.28
0.86
2.30
1.99
2.47
2.08
0.77
0.52
1.89
1.19
0.99
2.10
8.72
11.78
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

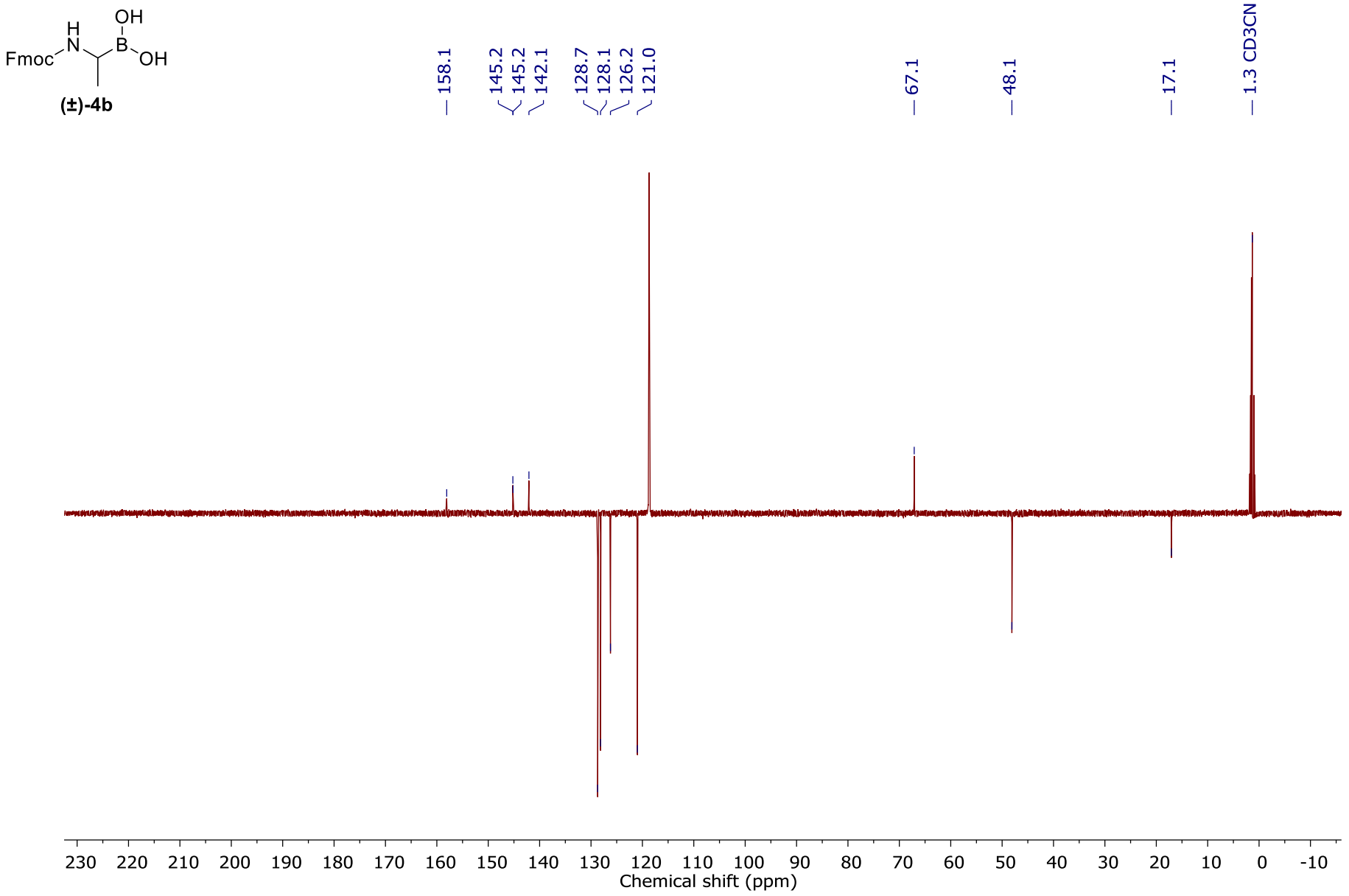

Fmoc
H
N
O
B
O
N
N
Boc
(±)-3t
157.2
147.1
144.2
141.8
141.4
136.3
127.7
127.1
125.4
120.0
113.9
85.6
83.9
77.2 CDCl3
67.0
47.4
29.2
28.0
25.0
24.9
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

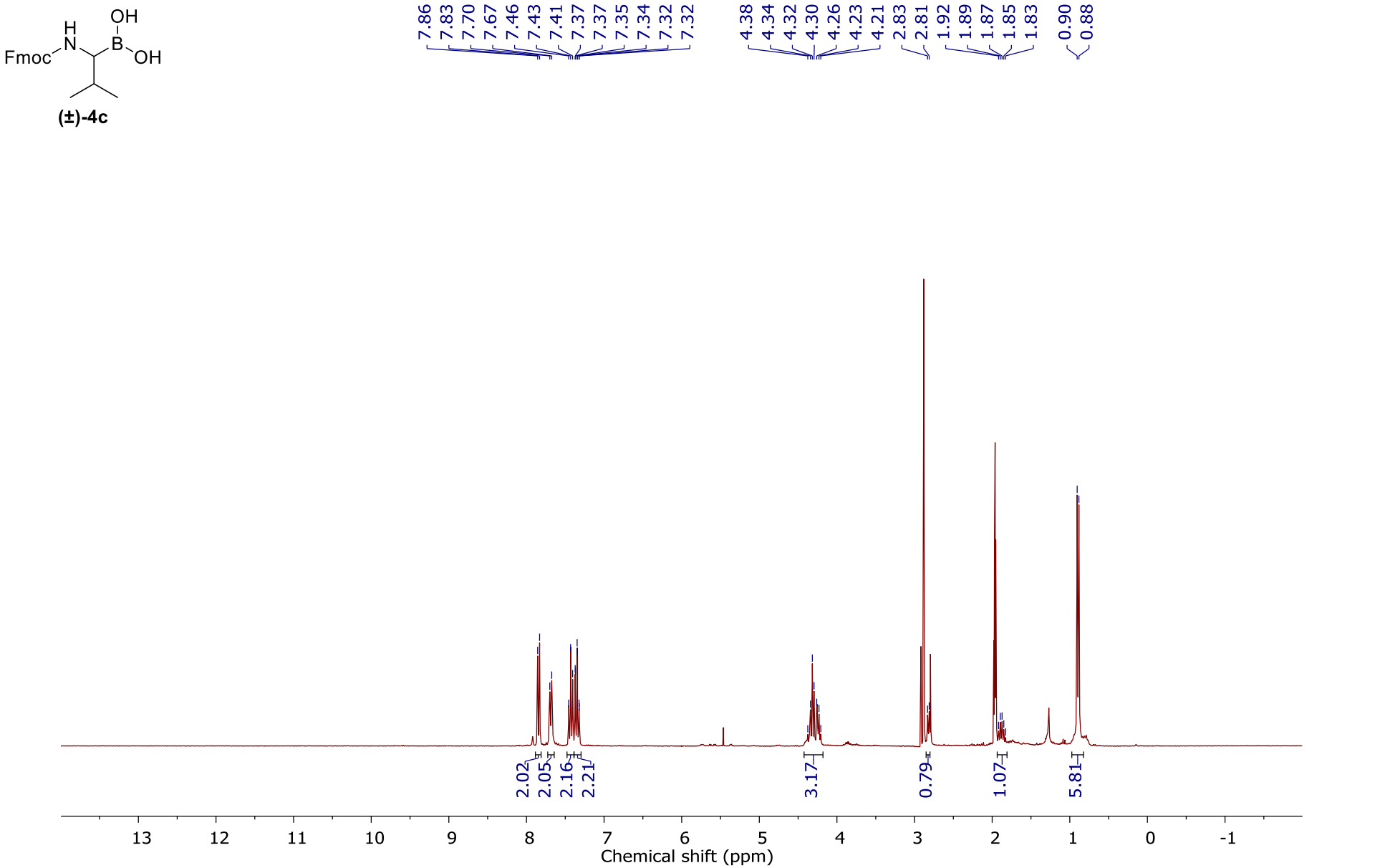
NMR spectra of α-aminoboronic acids

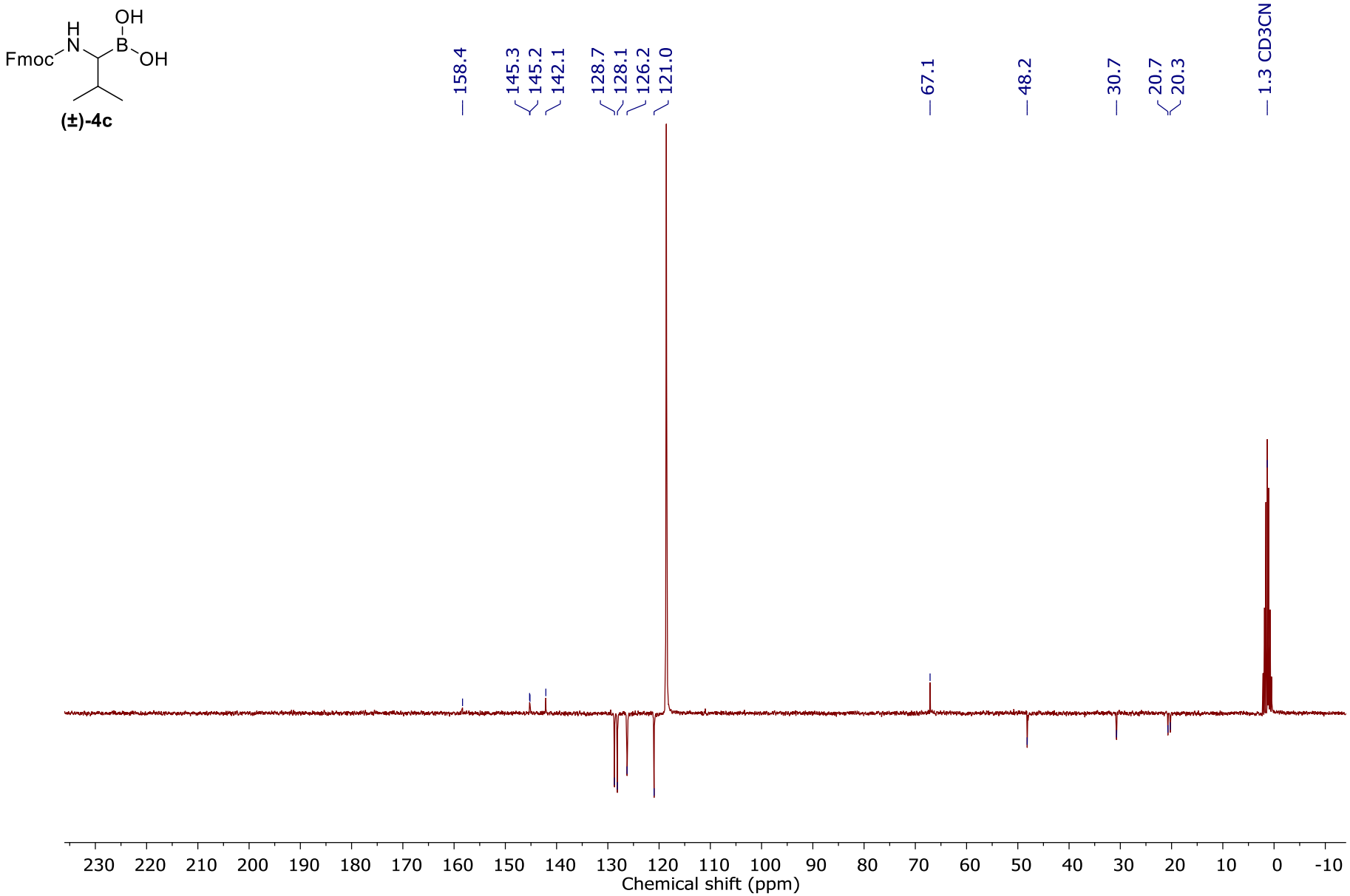

Fmoc
H
N
OH
B
OH
4a
7.82
7.81
7.66
7.64
7.42
7.40
7.39
7.34
7.34
7.33
7.32
7.31
7.31
4.30
4.29
4.22
4.20
4.19
2.61
1.94 CD3CN
2.00
1.97
2.07
2.07
2.04
0.87
1.71
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

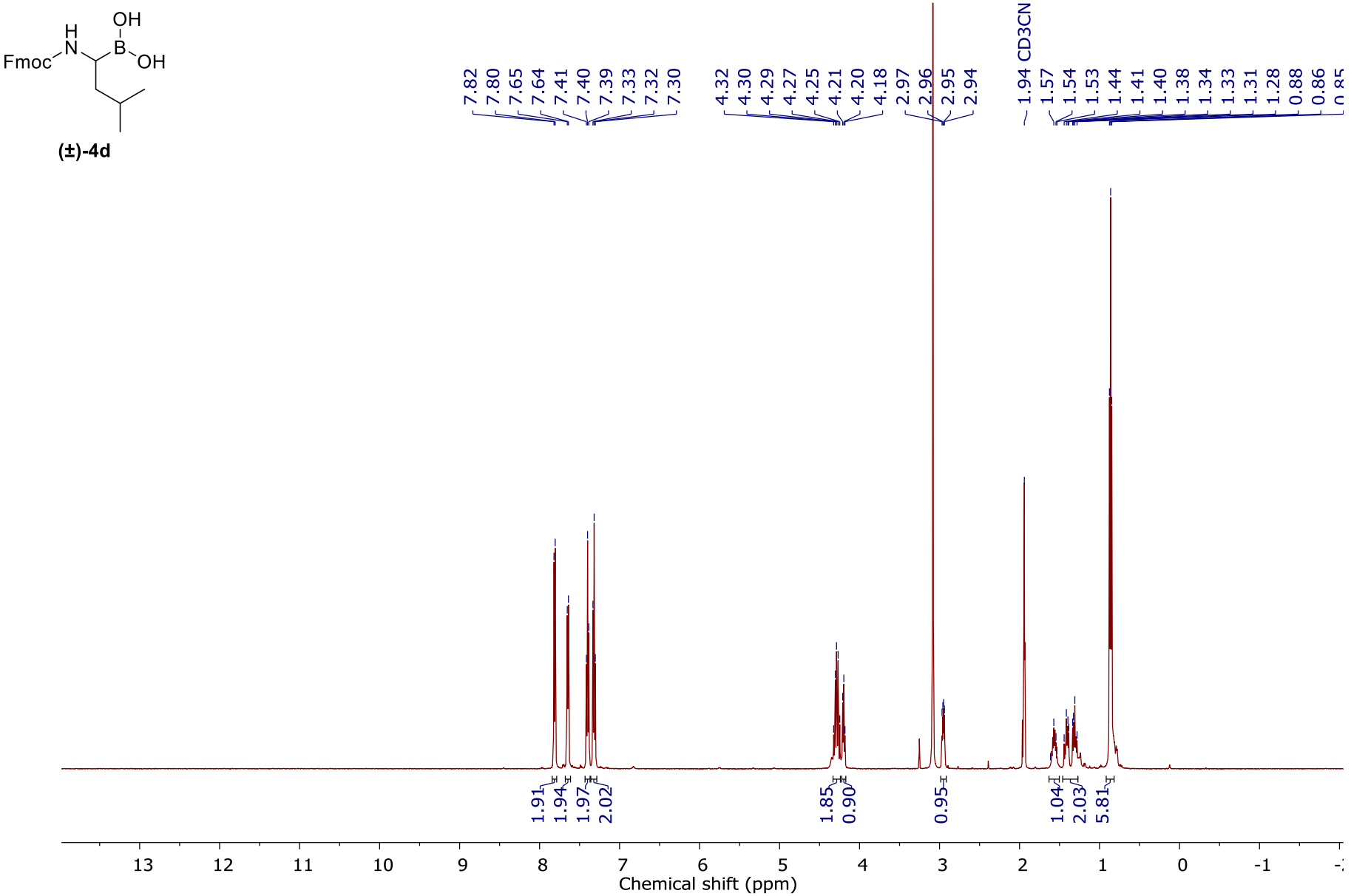

Fmoc
H
N
OH
B
OH
4a
158.6
145.2
142.1
128.7
128.2
126.2
121.0
67.2
48.1
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

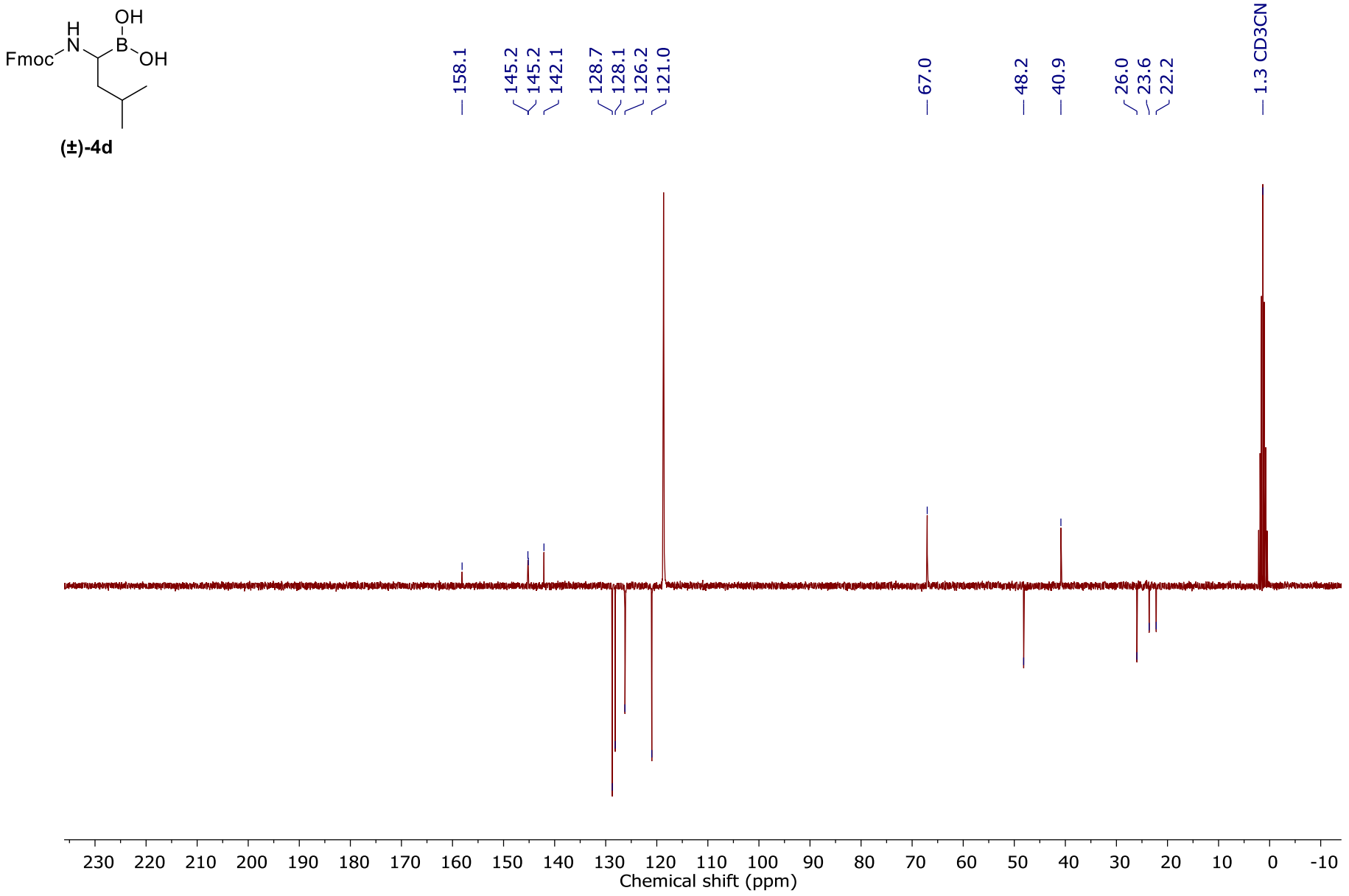

Fmoc
H
N
OH
B
OH
(±)-4b
7.82
7.80
7.66
7.64
7.41
7.40
7.38
7.34
7.32
7.31
4.32
4.30
4.29
4.28
4.26
4.21
4.20
4.18
2.95
2.94
2.92
2.91
1.94 CD3CN
1.12
1.10
1.96
1.97
2.00
2.04
2.08
0.97
1.04
2.88
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

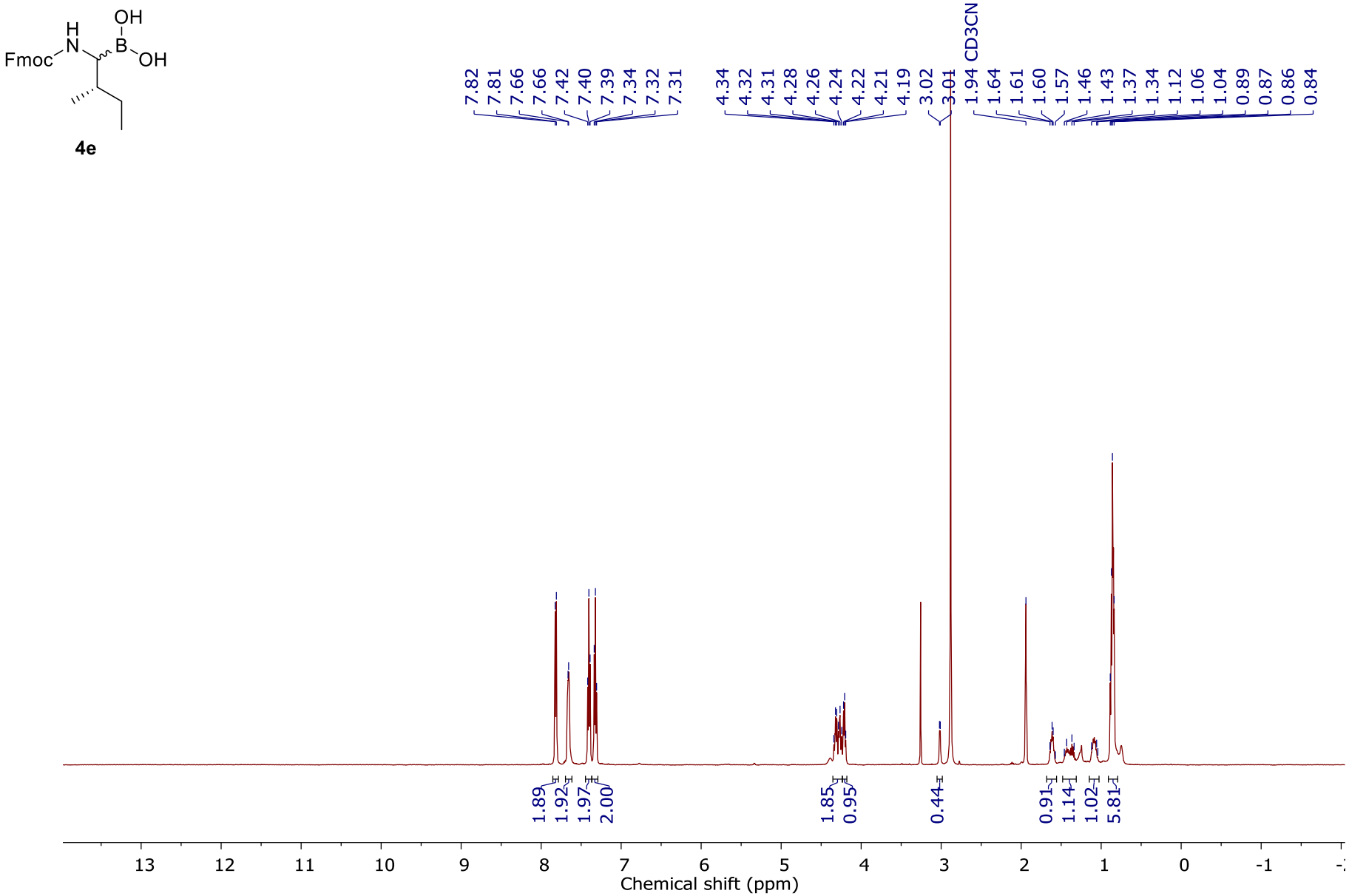

Fmoc
H
N
OH
B
OH
(±)-4b
158.1
145.2
145.2
142.1
128.7
128.1
126.2
121.0
67.1
48.1
17.1
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

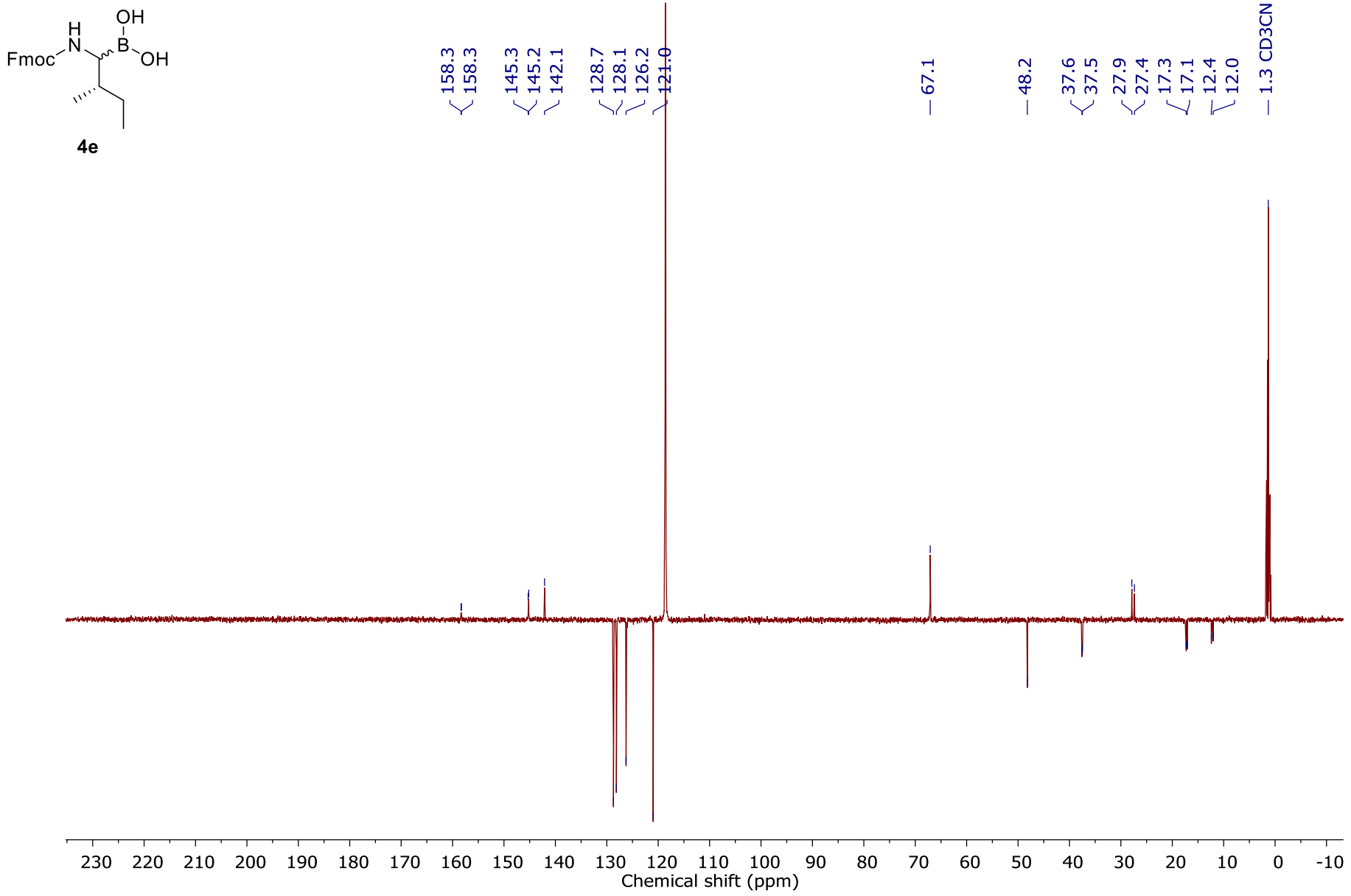

Fmoc
H
N
OH
B
OH
(±)-4c
7.86
7.83
7.70
7.67
7.46
7.43
7.41
7.37
7.37
7.35
7.34
7.32
7.32
4.38
4.34
4.32
4.30
4.26
4.23
4.21
2.83
2.81
1.92
1.89
1.87
1.85
1.83
0.90
0.88
2.02
2.05
2.16
2.21
3.17
0.79
1.07
5.81
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

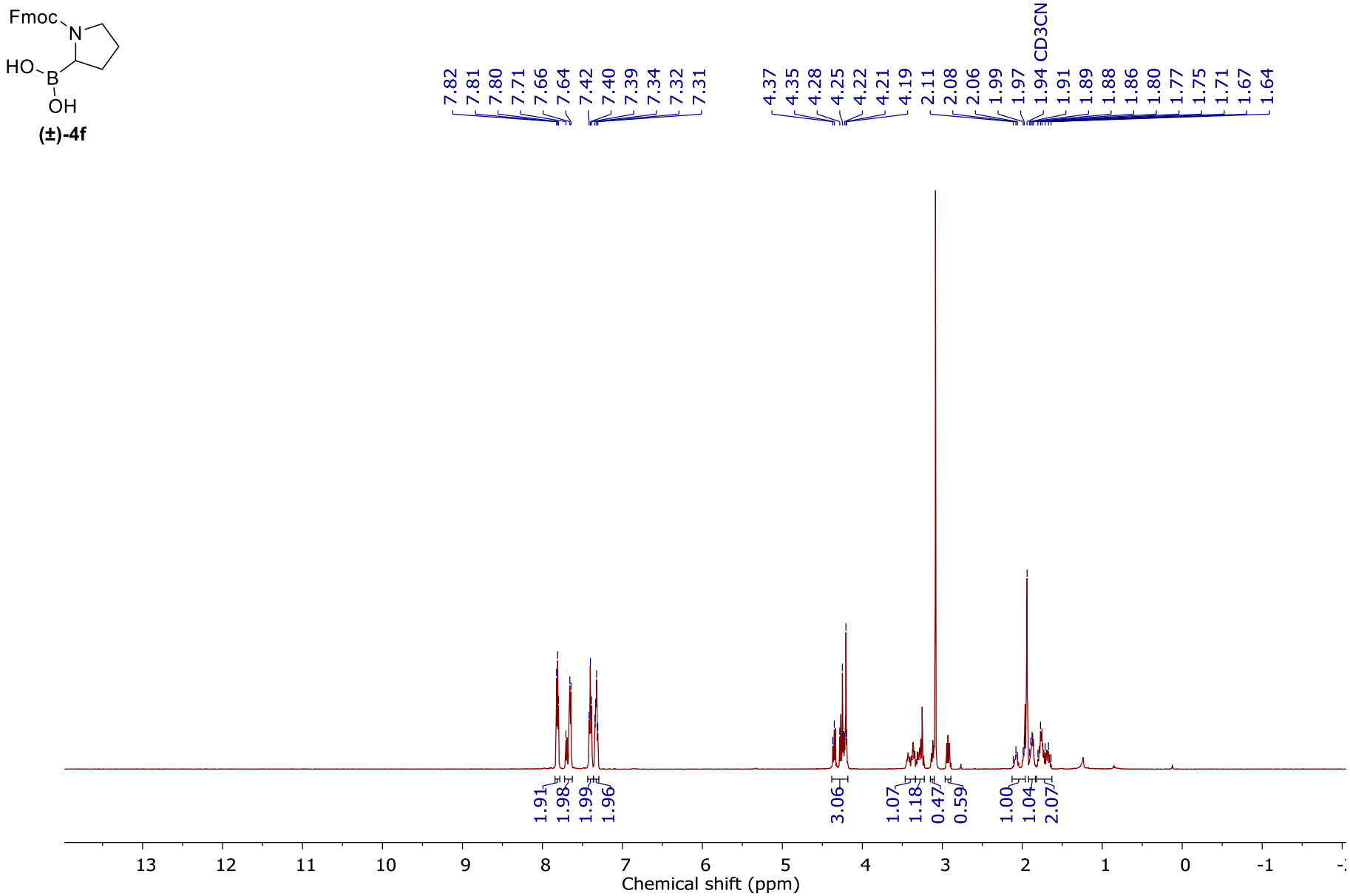

Fmoc
H
N
OH
B
OH
(±)-4c
158.4
145.3
145.2
142.1
128.7
128.1
126.2
121.0
67.1
48.2
30.7
20.7
20.3
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

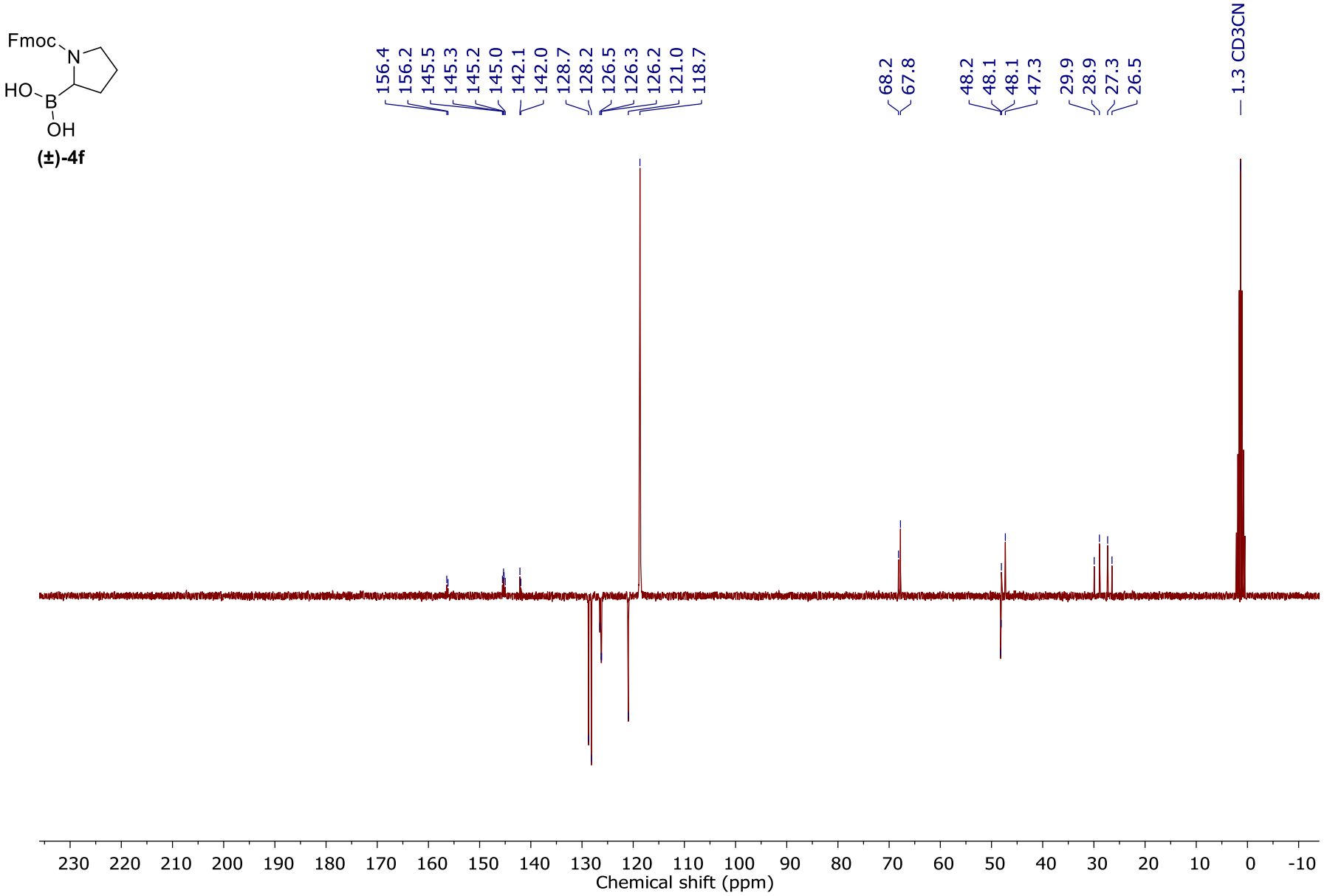

Fmoc
H
N
OH
B
OH
(±)-4d
7.82
7.80
7.65
7.64
7.41
7.40
7.39
7.33
7.32
7.30
4.32
4.30
4.29
4.27
4.25
4.21
4.20
4.18
2.97
2.96
2.95
2.94
1.94 CD3CN
1.57
1.54
1.53
1.44
1.41
1.40
1.38
1.34
1.33
1.31
1.28
0.88
0.86
1.91
1.94
1.97
2.02
1.85
0.90
0.95
1.04
2.03
5.81
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

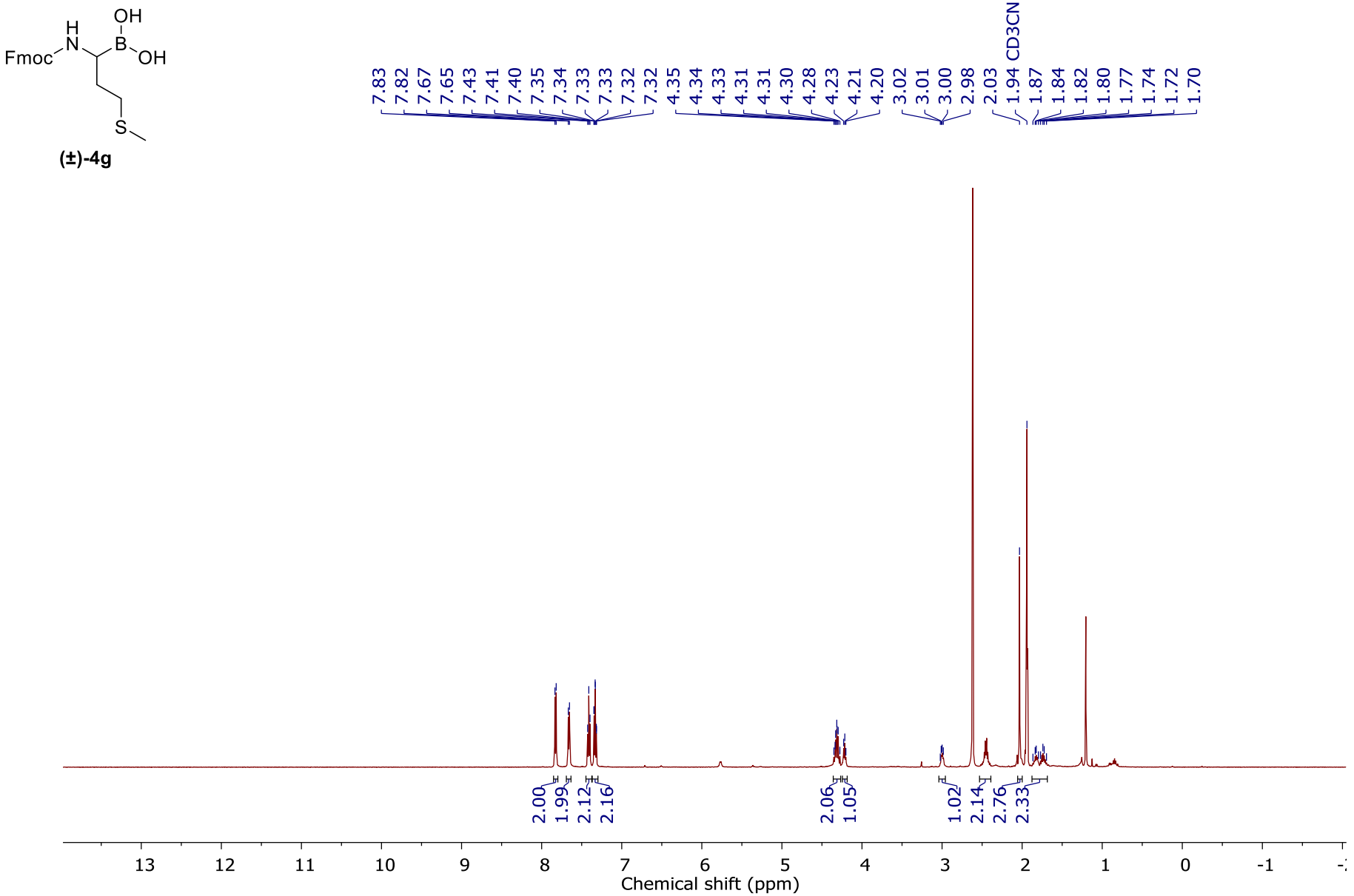

Fmoc
H
N
OH
B
OH
(±)-4d
158.1
145.2
145.2
142.1
128.7
128.1
126.2
121.0
67.0
48.2
40.9
26.0
23.6
22.2
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

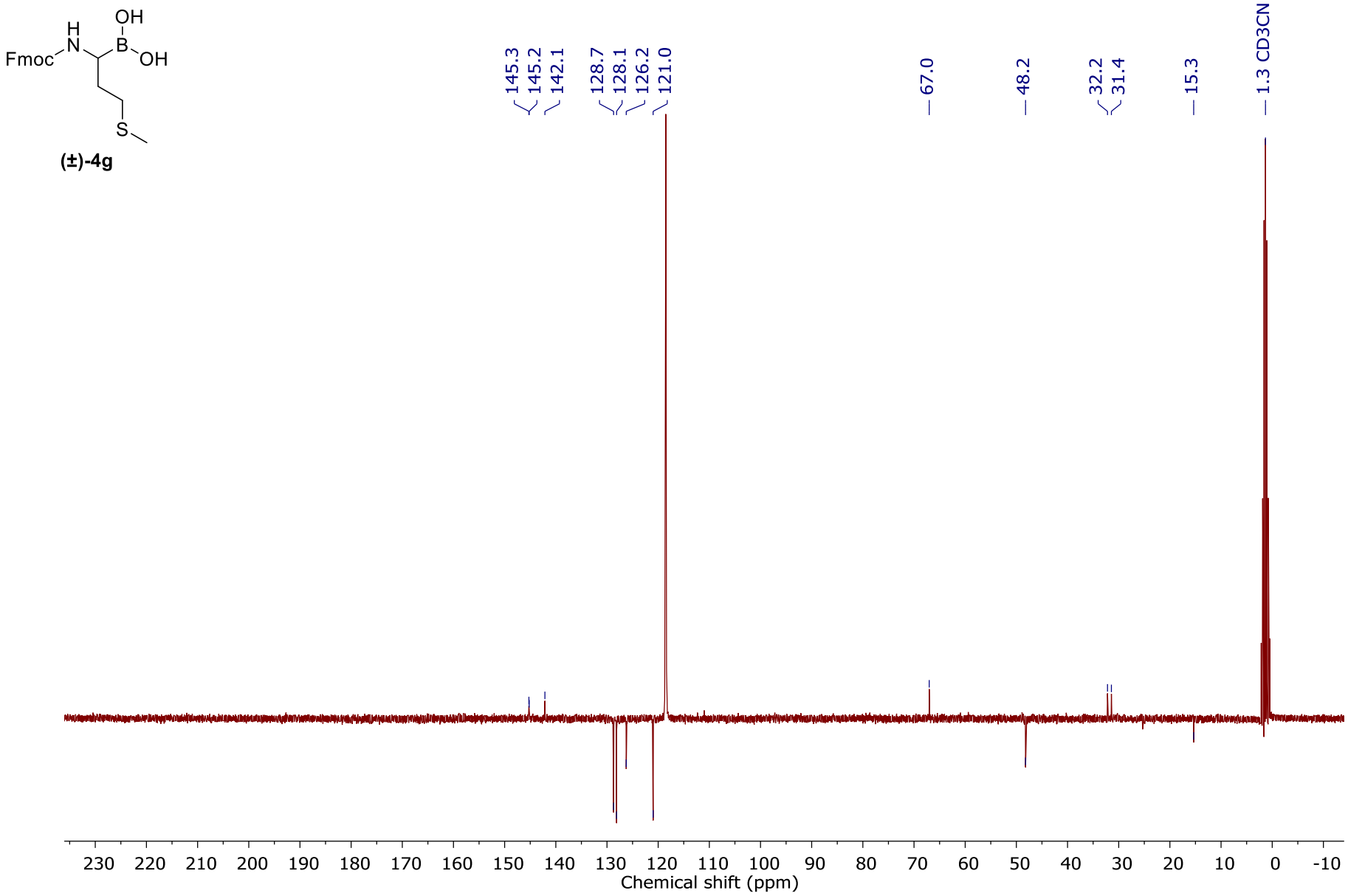

Fmoc
H
N
OH
B
OH
4e
7.82
7.81
7.66
7.66
7.42
7.40
7.39
7.34
7.32
7.31
4.34
4.32
4.31
4.28
4.26
4.24
4.22
4.21
4.19
3.02
3.01
1.94 CD3CN
1.64
1.61
1.60
1.57
1.46
1.43
1.37
1.34
1.12
1.06
1.04
0.89
0.87
0.86
0.84
1.89
1.92
1.97
2.00
1.85
0.95
0.44
0.91
1.14
1.02
5.81
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

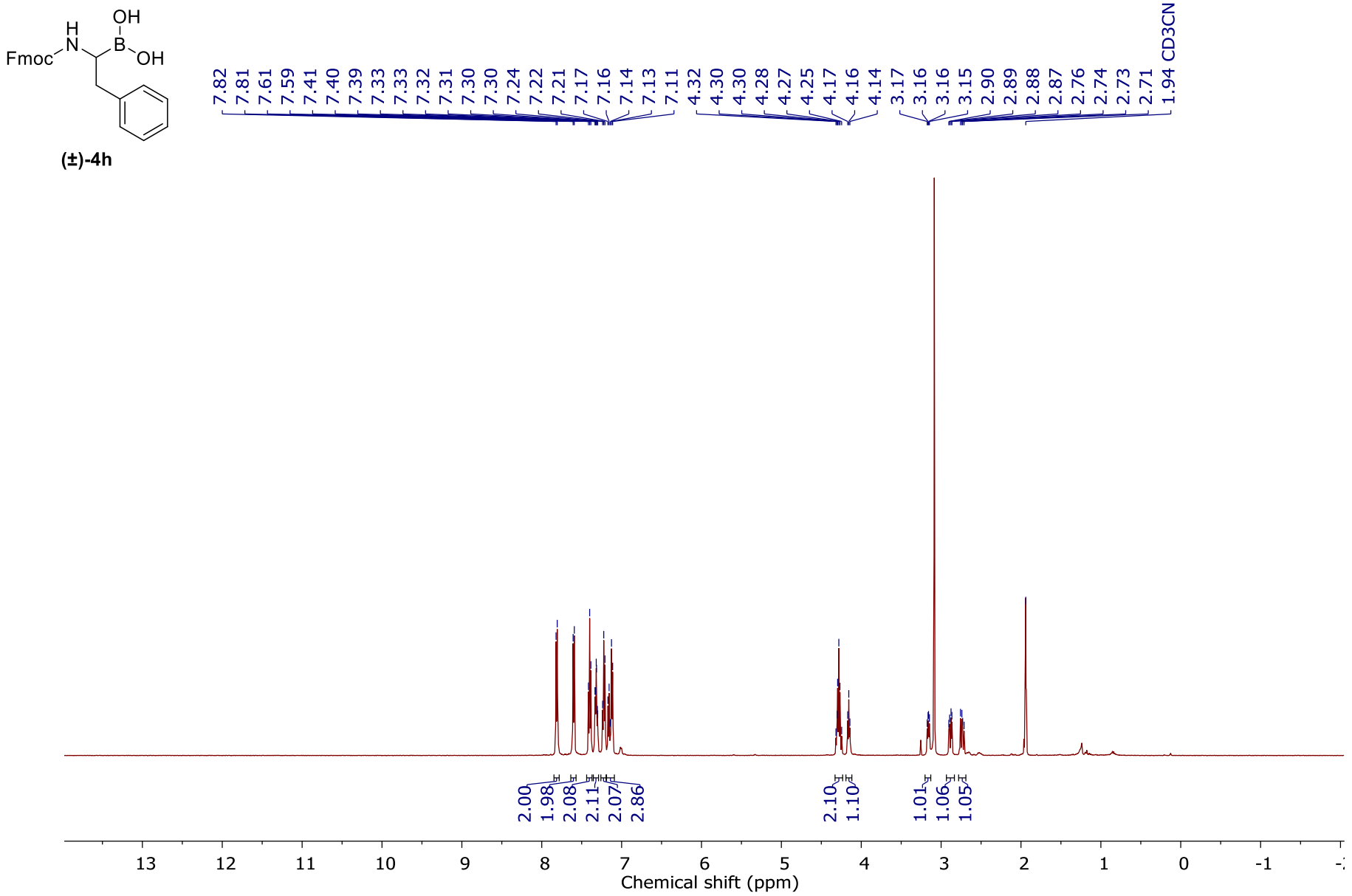

Fmoc
H
N
OH
B
OH
4e
158.3
158.3
145.3
145.2
142.1
128.7
128.1
126.2
121.0
67.1
48.2
37.6
37.5
27.9
27.4
17.3
17.1
12.4
12.0
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

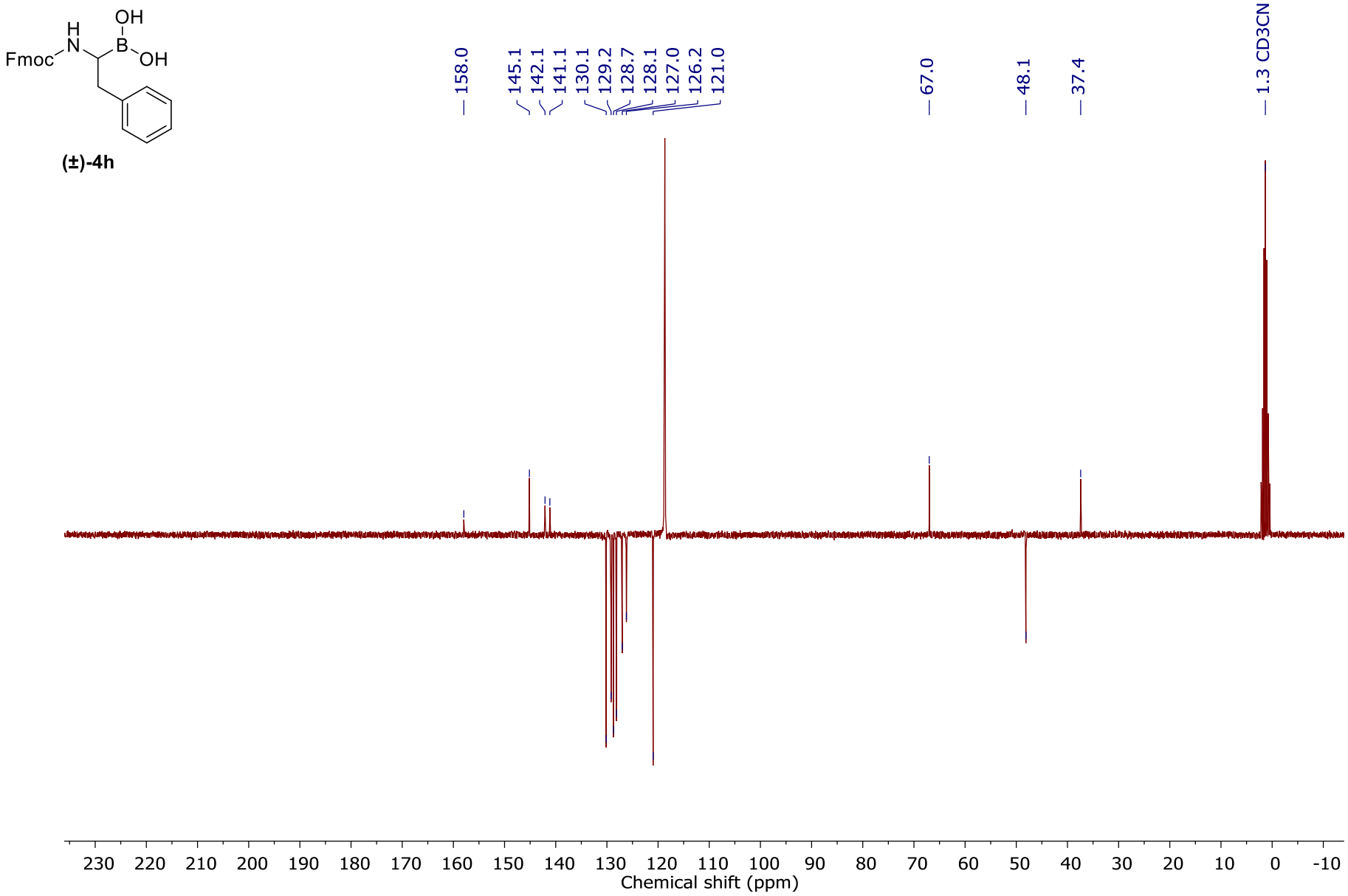

Fmoc
N
HO
B
OH
(±)-4f
7.82
7.81
7.80
7.71
7.66
7.64
7.42
7.40
7.39
7.34
7.32
7.31
4.37
4.35
4.28
4.25
4.22
4.21
4.19
2.11
2.08
2.06
1.99
1.97
1.94 CD3CN
1.91
1.89
1.88
1.86
1.80
1.77
1.75
1.71
1.67
1.64
1.91
1.98
1.99
1.96
3.06
1.07
1.18
0.47
0.59
1.00
1.04
2.07
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

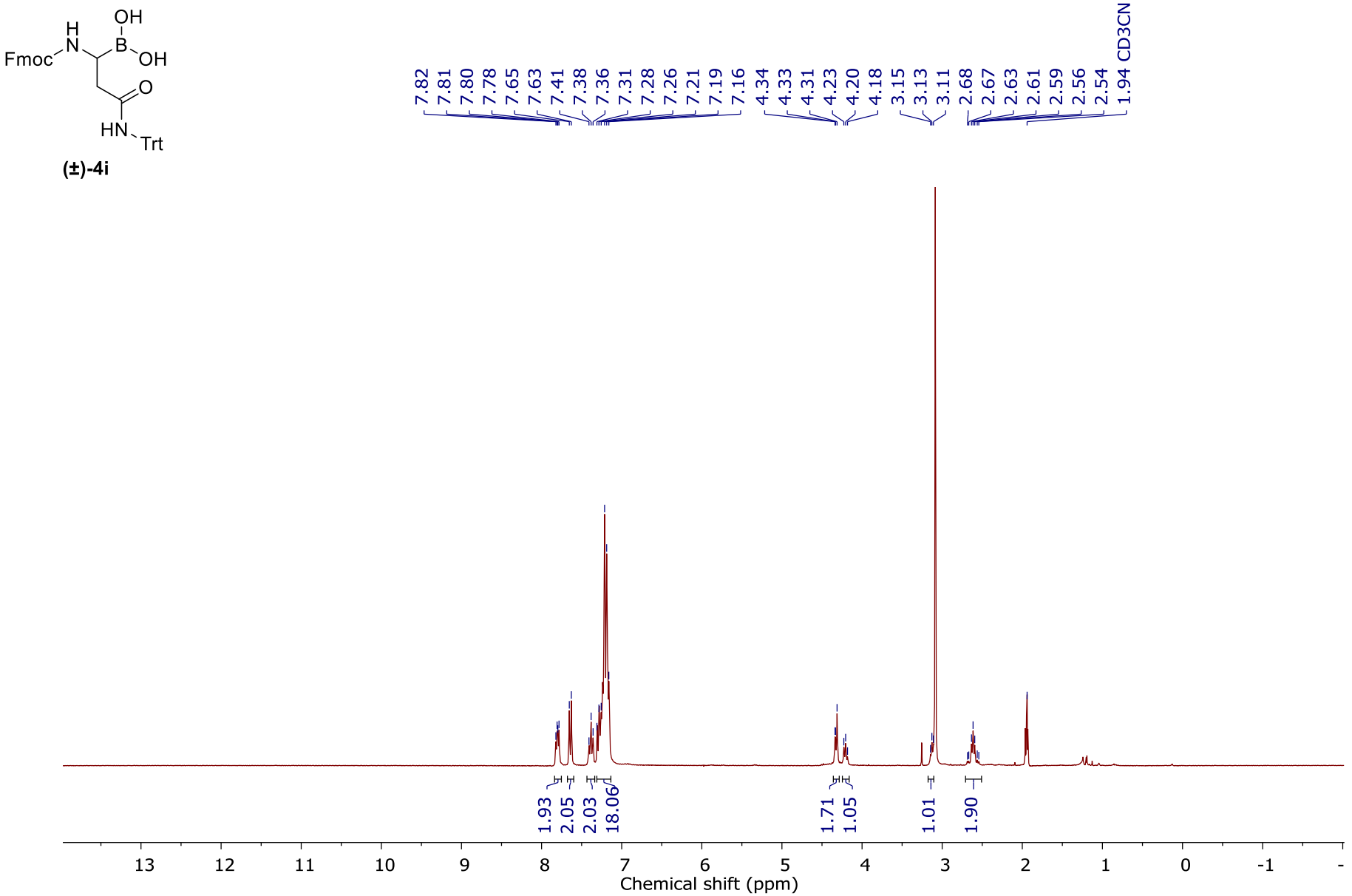

Fmoc
N
HO
B
OH
(±)-4f
156.4
156.2
145.5
145.3
145.2
145.0
142.1
142.0
128.7
128.2
126.5
126.3
126.2
121.0
118.7
68.2
67.8
48.2
48.1
48.1
47.3
29.9
28.9
27.3
26.5
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

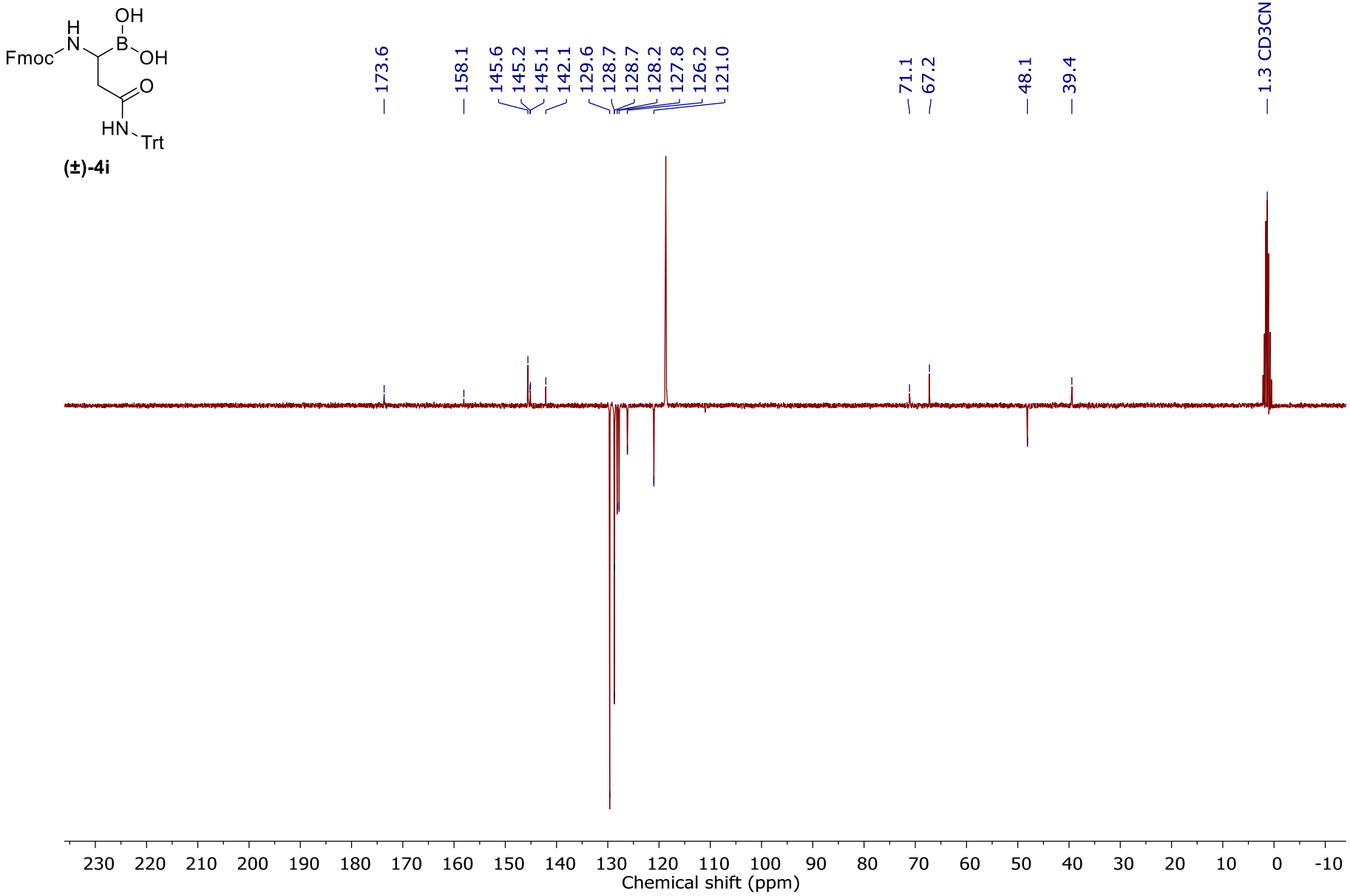

OH
H
N
B
OH
Fmoc
S
(±)-4g
7.83
7.82
7.67
7.65
7.43
7.41
7.40
7.35
7.34
7.33
7.33
7.32
7.32
4.35
4.34
4.33
4.31
4.31
4.30
4.28
4.23
4.21
4.20
3.02
3.01
3.00
2.98
2.03
1.94 CD3CN
1.87
1.84
1.82
1.80
1.77
1.74
1.72
1.70
2.00
1.99
2.12
2.16
2.06
1.05
1.02
2.14
2.76
2.33
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

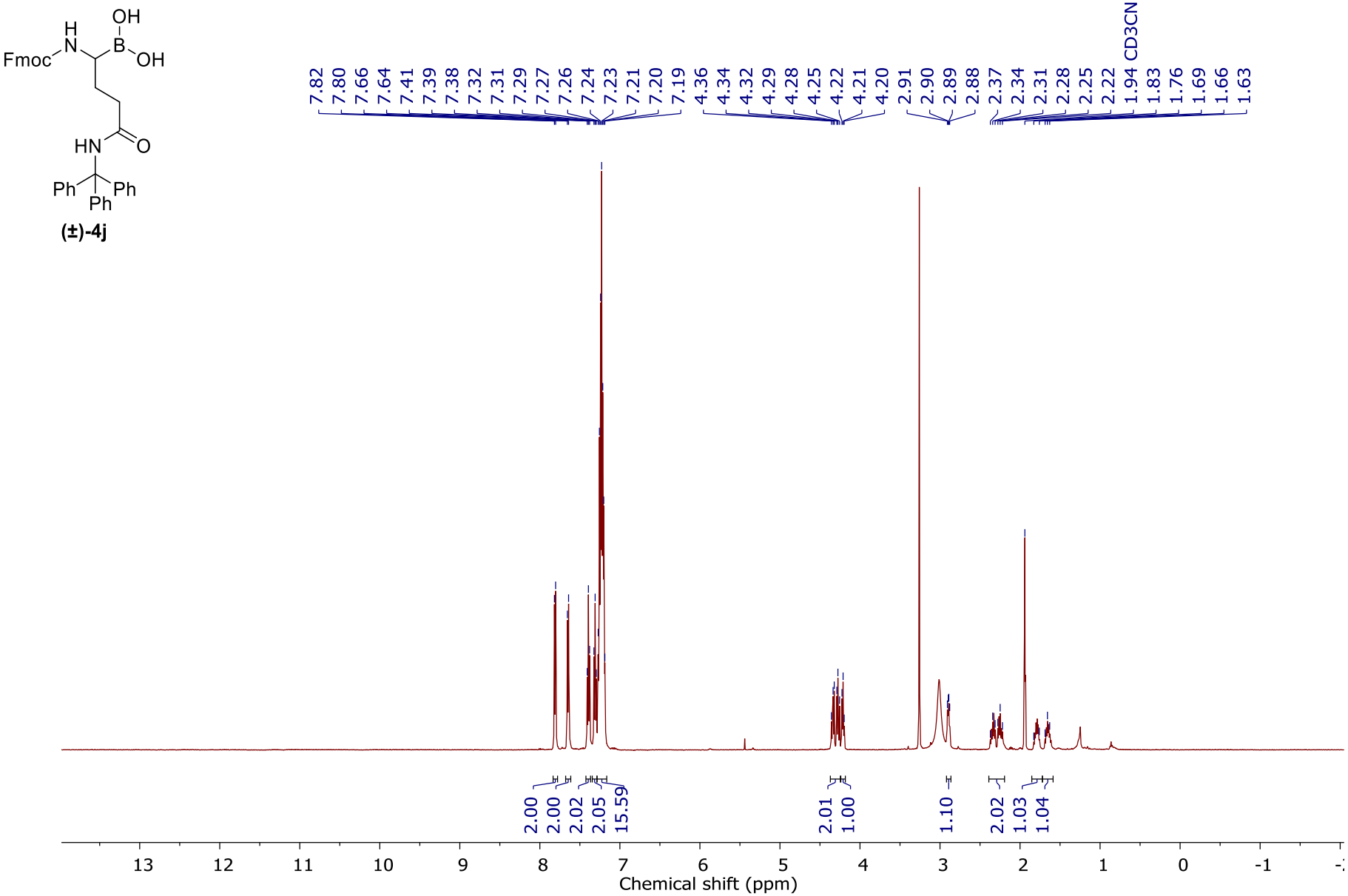

Fmoc
H
N
OH
B
OH
S
(±)-4g
145.3
145.2
142.1
128.7
128.1
126.2
121.0
67.0
48.2
32.2
31.4
15.3
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

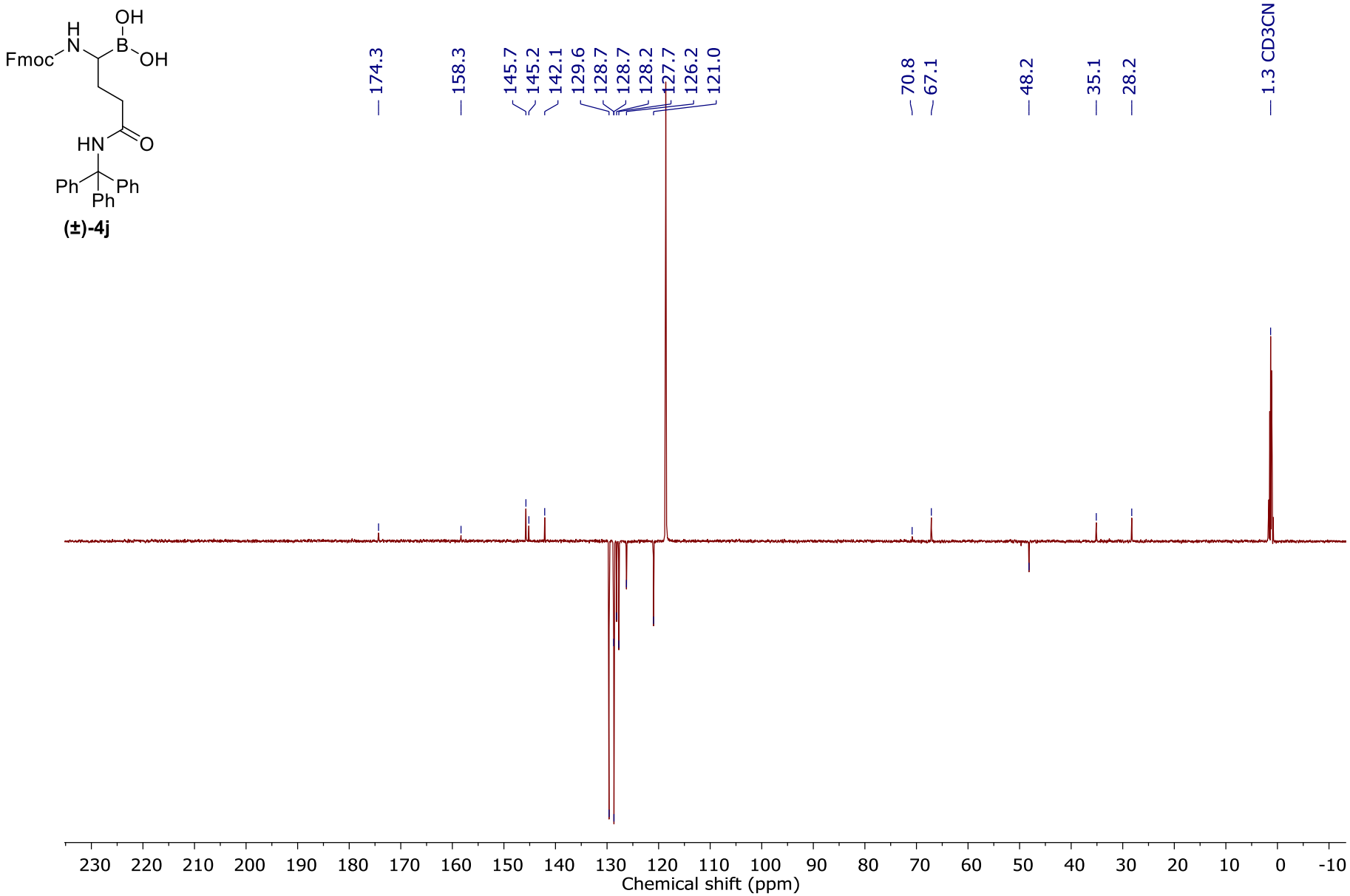

Fmoc
H
N
OH
B
OH
(±)-4h
7.82
7.81
7.61
7.59
7.41
7.40
7.39
7.33
7.33
7.32
7.31
7.30
7.30
7.24
7.22
7.21
7.17
7.16
7.14
7.13
7.11
4.32
4.30
4.30
4.28
4.27
4.25
4.17
4.16
4.14
3.17
3.16
3.16
3.15
2.90
2.89
2.88
2.87
2.76
2.74
2.73
2.71
1.94 CD3CN
2.00
1.98
2.08
2.11
2.07
2.86
2.10
1.10
1.01
1.06
1.05
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

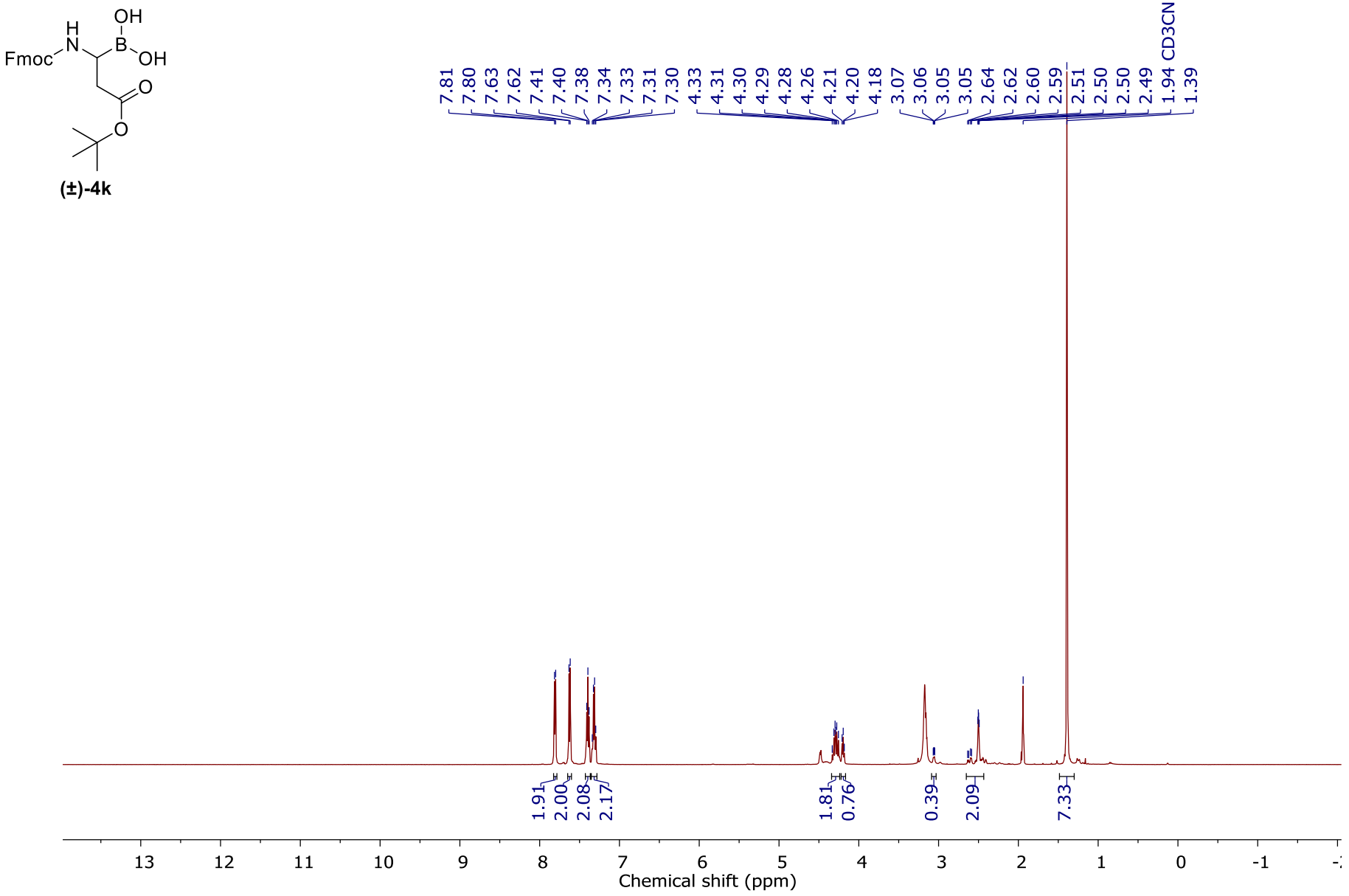

Fmoc
H
N
OH
B
OH
(±)-4h
158.0
145.1
142.1
141.1
130.1
129.2
128.7
128.1
127.0
126.2
121.0
67.0
48.1
37.4
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

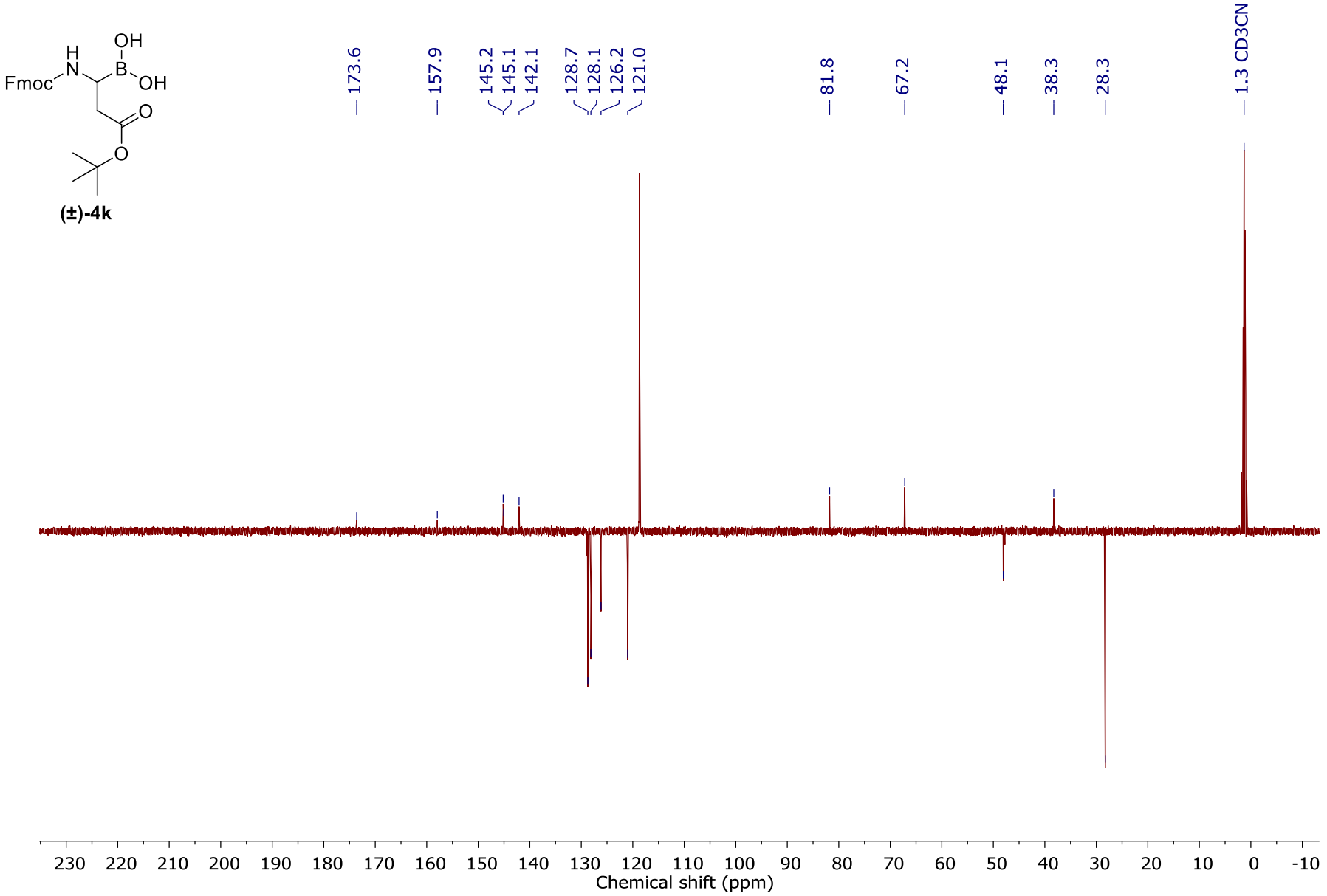

OH
H
N
B
OH
Fmoc
O
HN
Trt
(±)-4i
7.82
7.81
7.80
7.78
7.65
7.63
7.41
7.38
7.36
7.31
7.28
7.26
7.21
7.19
7.16
4.34
4.33
4.31
4.23
4.20
4.18
3.15
3.13
3.11
2.68
2.67
2.63
2.61
2.59
2.56
2.54
1.94 CD3CN
1.93
2.05
2.03
18.06
1.71
1.05
1.01
1.90
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-
Chemical shift (ppm)

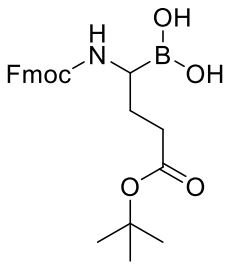

Fmoc
H
N
OH
B
OH
O
HN
Trt
(±)-4i
173.6
158.1
145.6
145.2
145.1
142.1
129.6
128.7
128.7
128.2
127.8
126.2
121.0
71.1
67.2
48.1
39.4
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
HN
O
Ph
Ph
Ph
(±)-4j
7.82
7.80
7.66
7.64
7.41
7.39
7.38
7.32
7.31
7.29
7.27
7.26
7.24
7.23
7.21
7.20
7.19
4.36
4.34
4.32
4.29
4.28
4.25
4.22
4.21
4.20
2.91
2.90
2.89
2.88
2.37
2.34
2.31
2.28
2.25
2.22
1.94 CD3CN
1.83
1.76
1.69
1.66
1.63
2.00
2.00
2.02
2.05
15.59
2.01
1.00
1.10
2.02
1.03
1.04
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
HN
O
Ph
Ph
Ph
(±)-4j
174.3
158.3
145.7
145.2
142.1
129.6
128.7
128.7
128.2
127.7
126.2
121.0
70.8
67.1
48.2
35.1
28.2
1.3 CD3CN
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
Chemical shift (ppm)

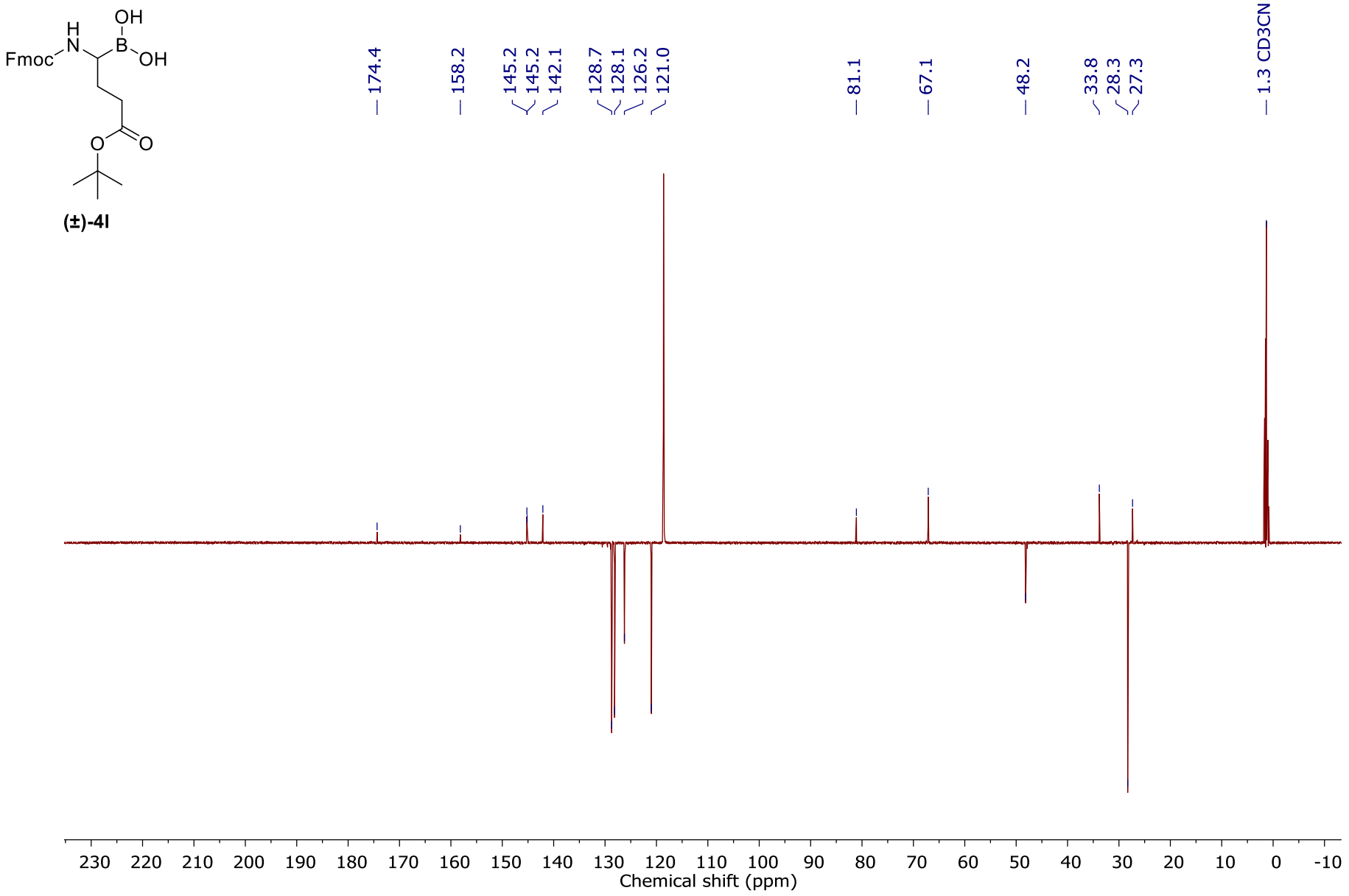

Fmoc
H
N
OH
B
OH
O
O
(±)-4k
7.81
7.80
7.63
7.62
7.41
7.40
7.38
7.34
7.33
7.31
7.30
4.33
4.31
4.30
4.29
4.28
4.26
4.21
4.20
4.18
3.07
3.06
3.05
3.05
2.64
2.62
2.60
2.59
2.51
2.50
2.50
2.49
1.94 CD3CN
1.39
1.91
2.00
2.08
2.17
1.81
0.76
0.39
2.09
7.33
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

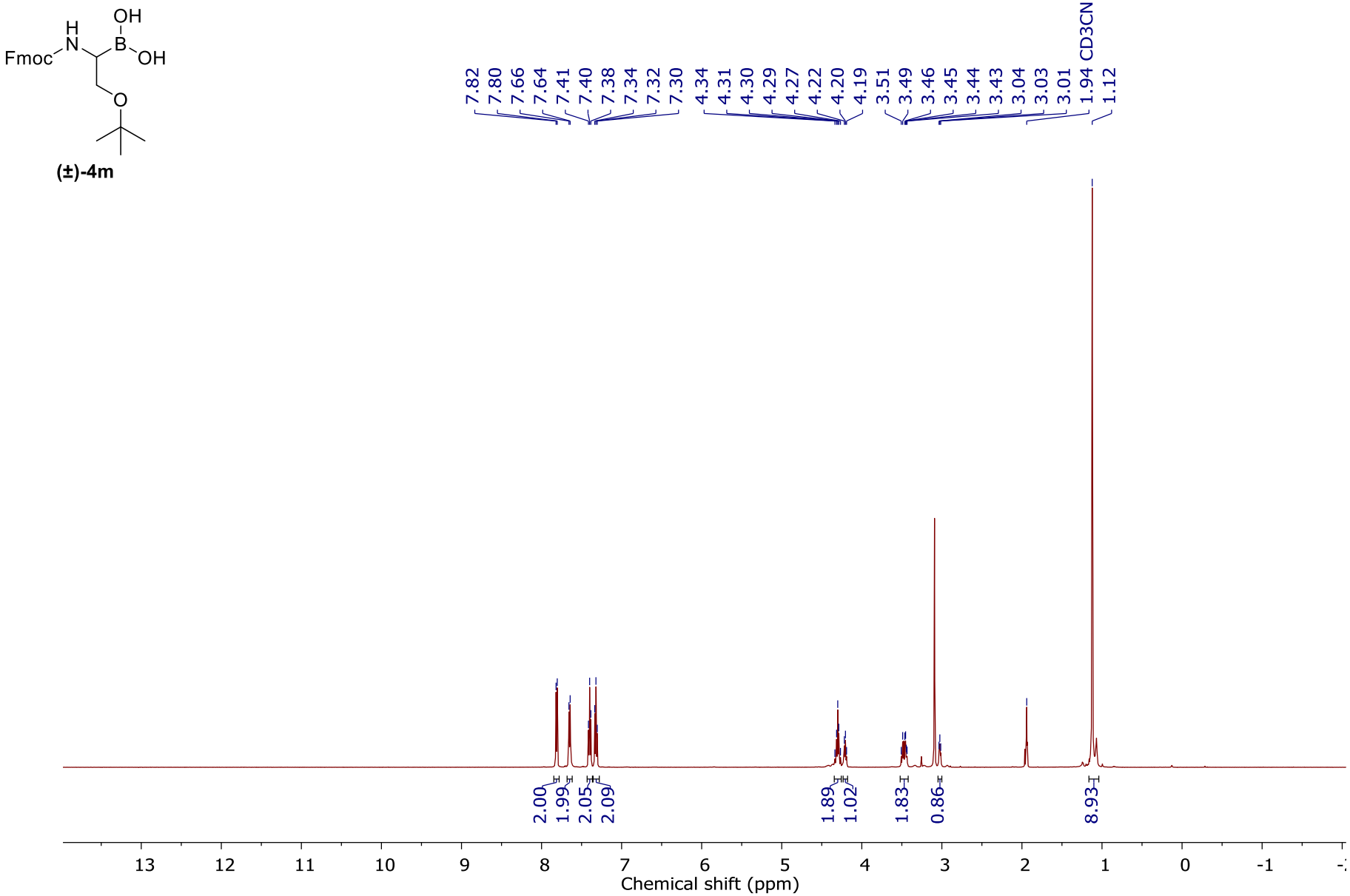

Fmoc
H
N
OH
B
OH
O
O
(±)-4k
173.6
157.9
145.2
145.1
142.1
128.7
128.1
126.2
121.0
81.8
67.2
48.1
38.3
28.3
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

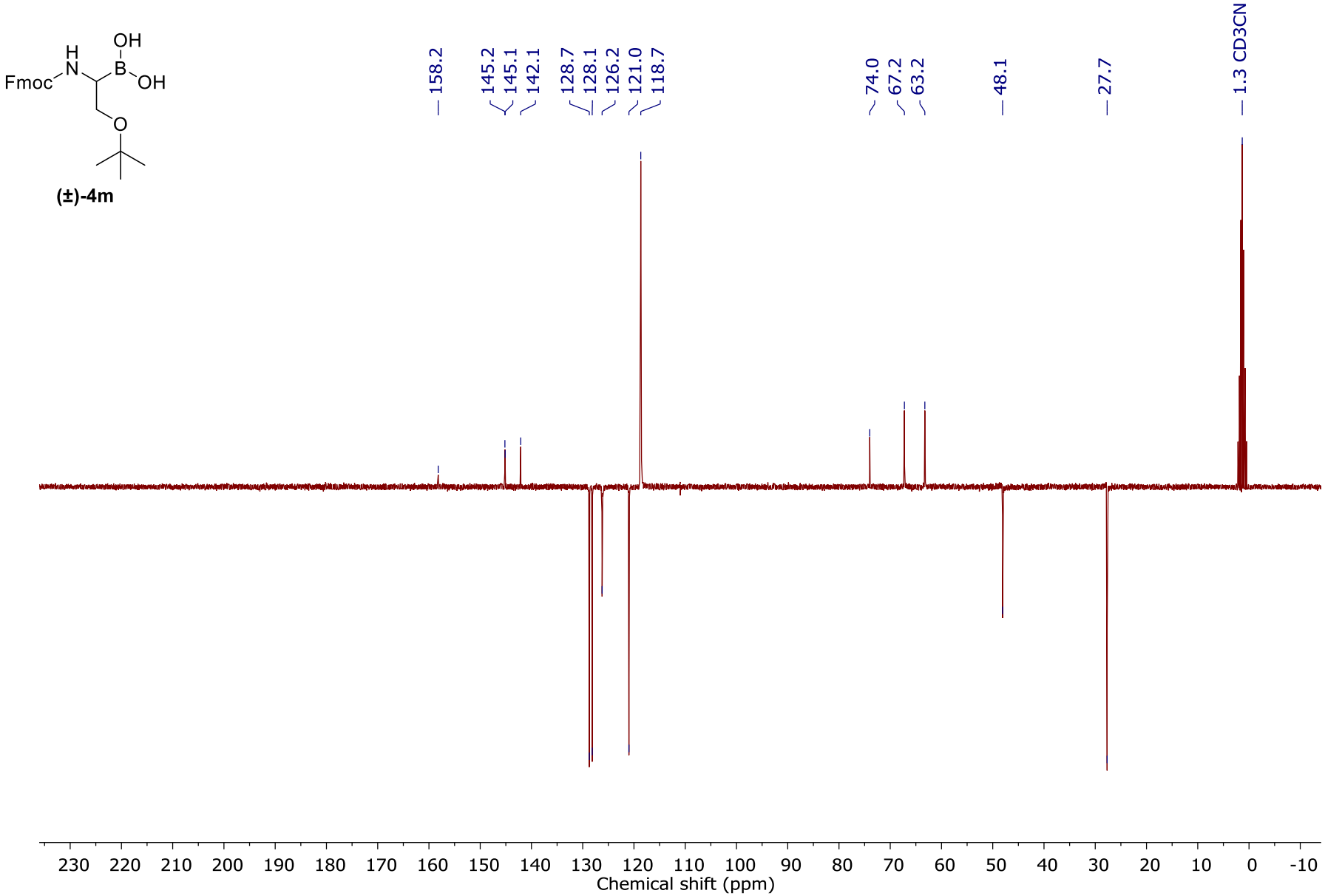

OH
H
N
B
OH
Fmoc
O
O

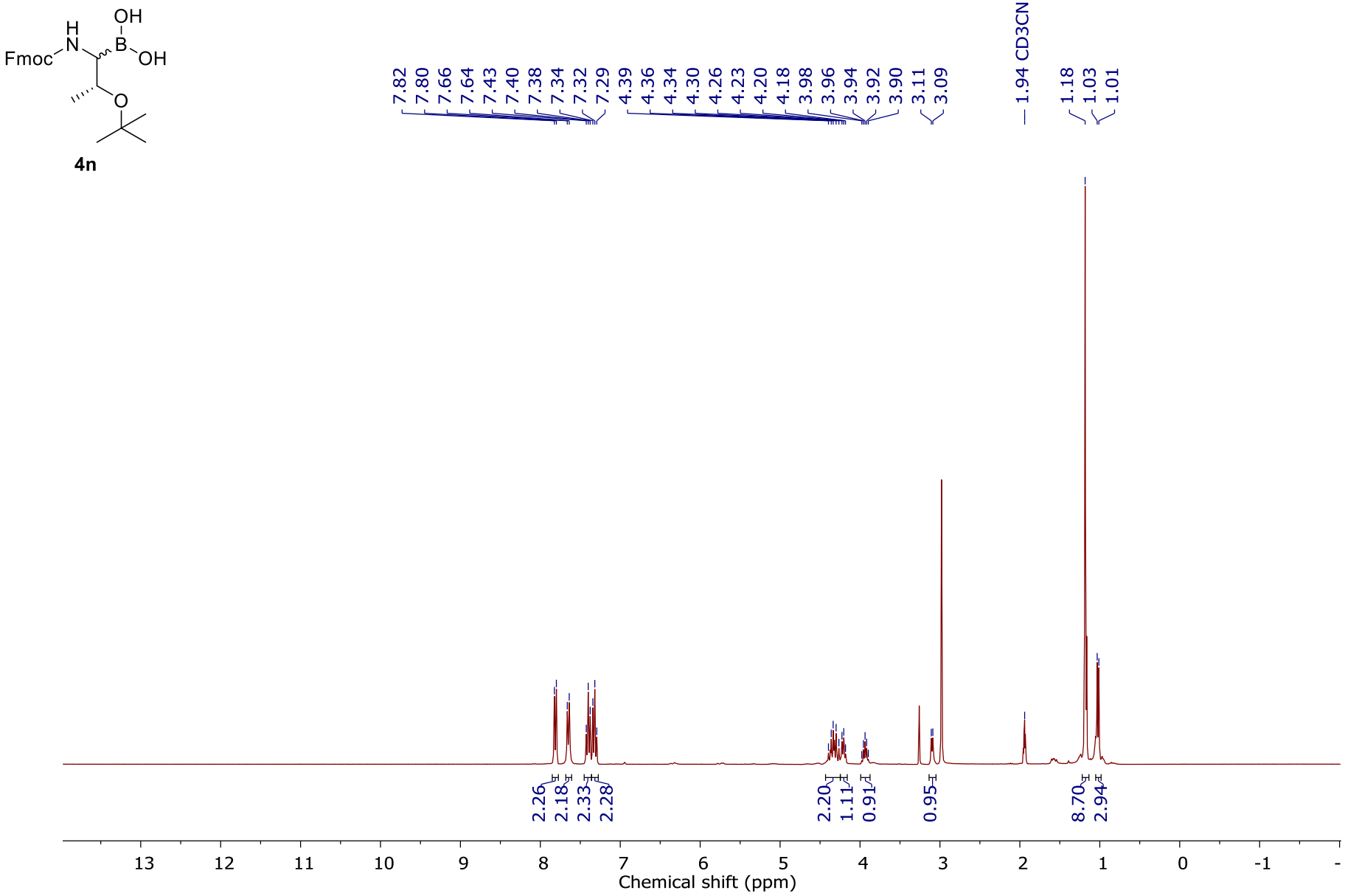
(±)-4l

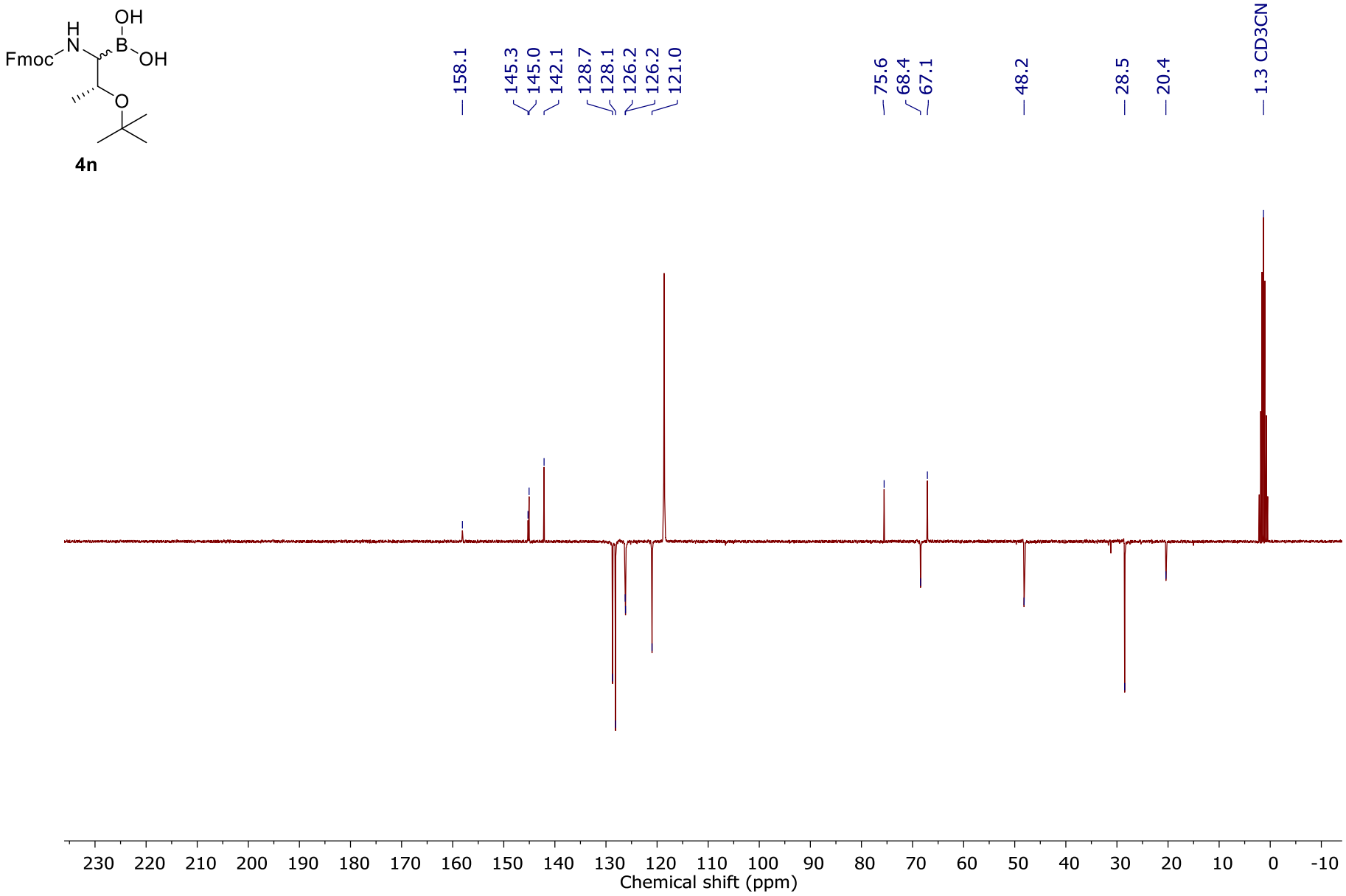
7.82
7.81
7.66
7.64
7.41
7.40
7.39
7.34
7.32
7.31
4.34
4.32
4.32
4.30
4.29
4.26
4.22
4.20
4.19
2.92
2.91
2.90
2.89
2.21
2.19
2.18
1.94 CD3CN
1.85
1.83
1.82
1.81
1.79
1.78
1.69
1.68
1.67
1.65
1.63
1.40
2.00
2.01
2.06
2.18
1.96
0.99
1.08
1.83
1.07
1.21
8.88
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

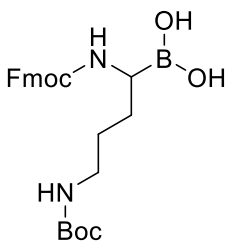

Fmoc
H
N
OH
B
OH
O
O
(±)-4l
174.4
158.2
145.2
145.2
142.1
128.7
128.1
126.2
121.0
81.1
67.1
48.2
33.8
28.3
27.3
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
O
(±)-4m
7.82
7.80
7.66
7.64
7.41
7.40
7.38
7.34
7.32
7.30
4.34
4.31
4.30
4.29
4.27
4.22
4.20
4.19
3.51
3.49
3.46
3.45
3.44
3.43
3.04
3.03
3.01
1.94 CD3CN
1.12
2.00
1.99
2.05
2.09
1.89
1.02
1.83
0.86
8.93
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
O
(±)-4m
158.2
145.2
145.1
142.1
128.7
128.1
126.2
121.0
118.7
74.0
67.2
63.2
48.1
27.7
1.3 CD3CN
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
Chemical shift (ppm)

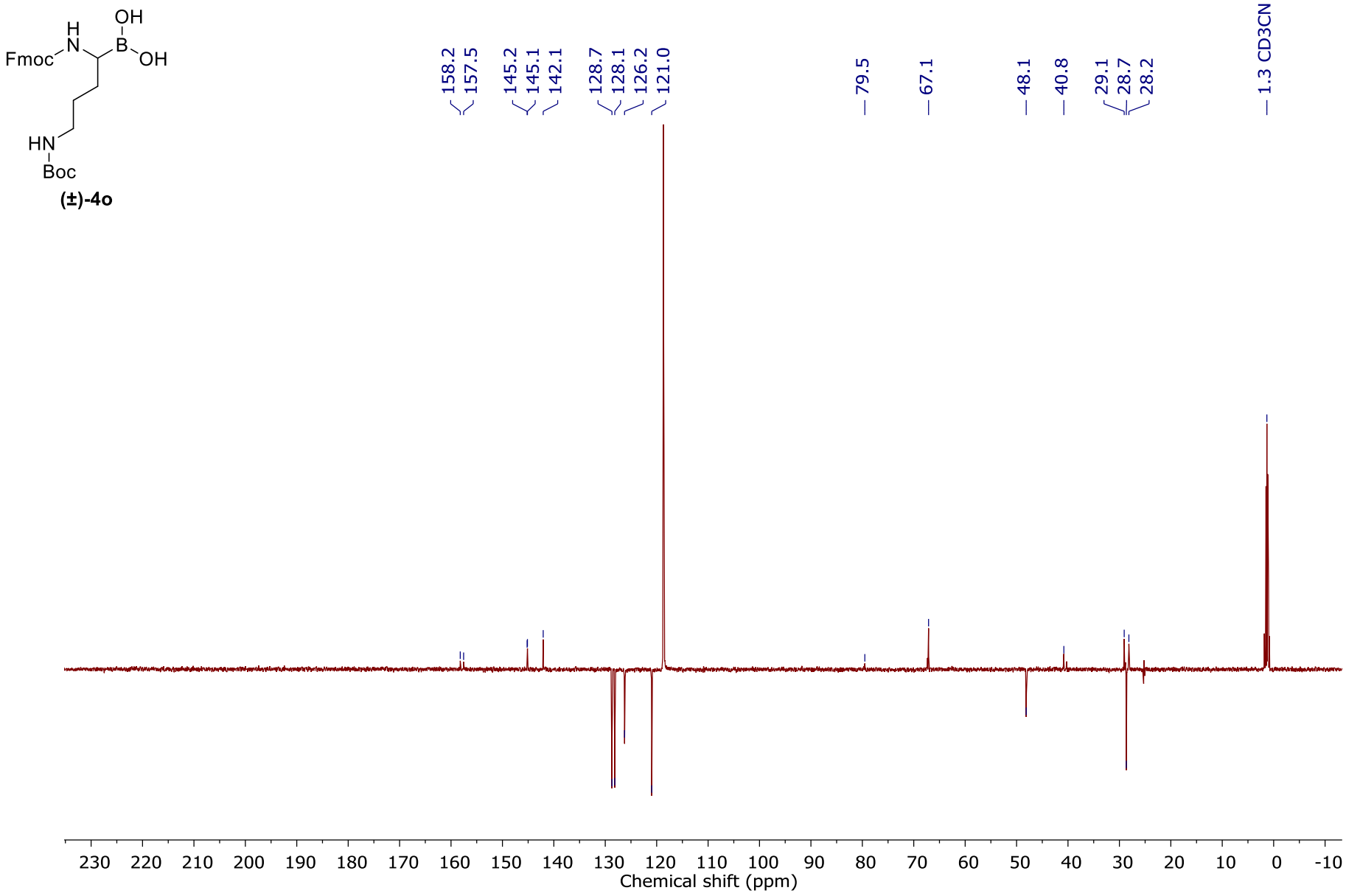

Fmoc
H
N
OH
B
OH
O
4n
7.82
7.80
7.66
7.64
7.43
7.40
7.38
7.34
7.32
7.29
4.39
4.36
4.34
4.30
4.26
4.23
4.20
4.18
3.98
3.96
3.94
3.92
3.90
3.11
3.09
1.94 CD3CN
1.18
1.03
1.01
2.26
2.18
2.33
2.28
2.20
1.11
0.91
0.95
8.70
2.94
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

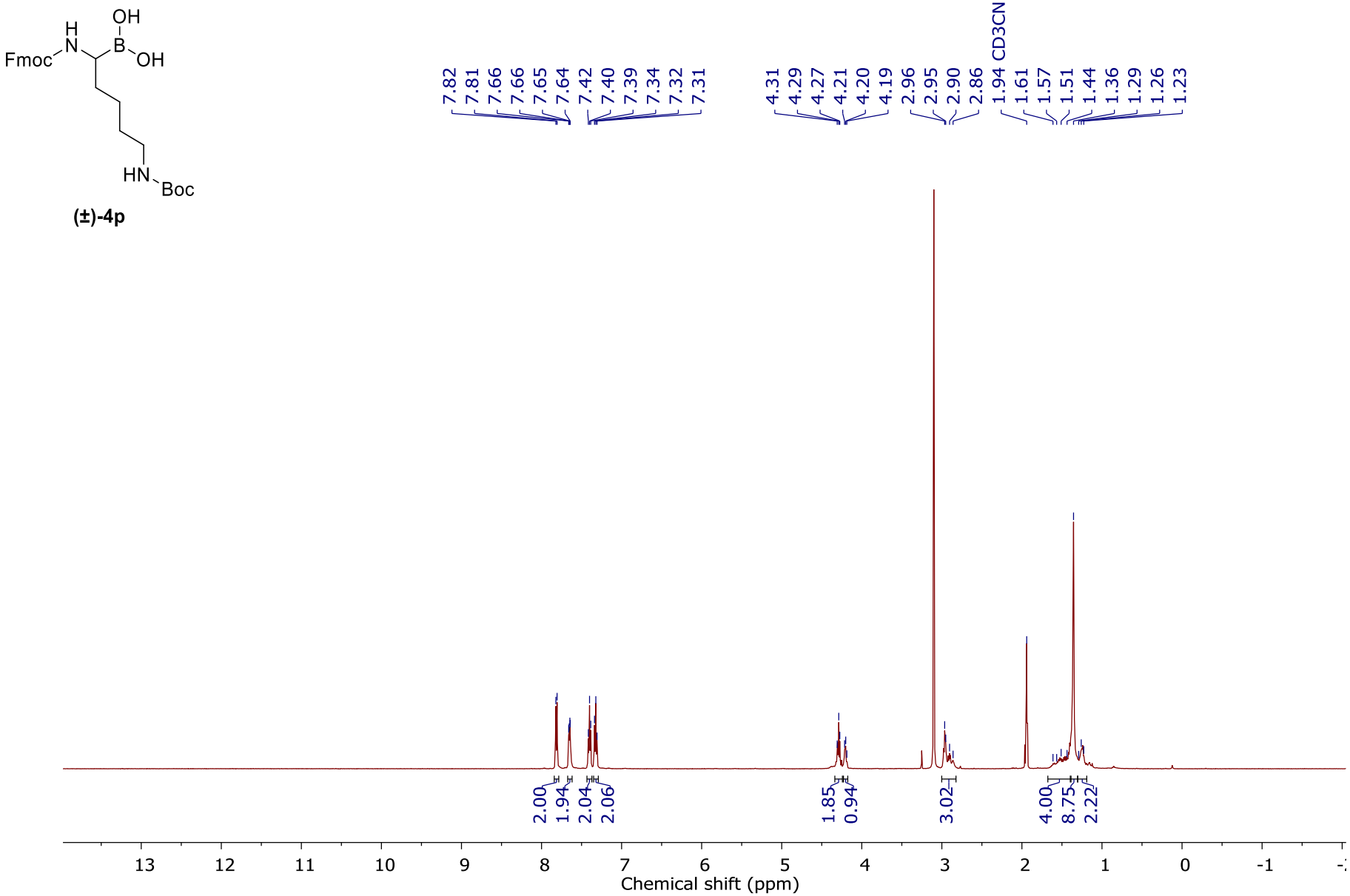

Fmoc
H
N
OH
B
OH
O
4n
158.1
145.3
145.0
142.1
128.7
128.1
126.2
126.2
121.0
75.6
68.4
67.1
48.2
28.5
20.4
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

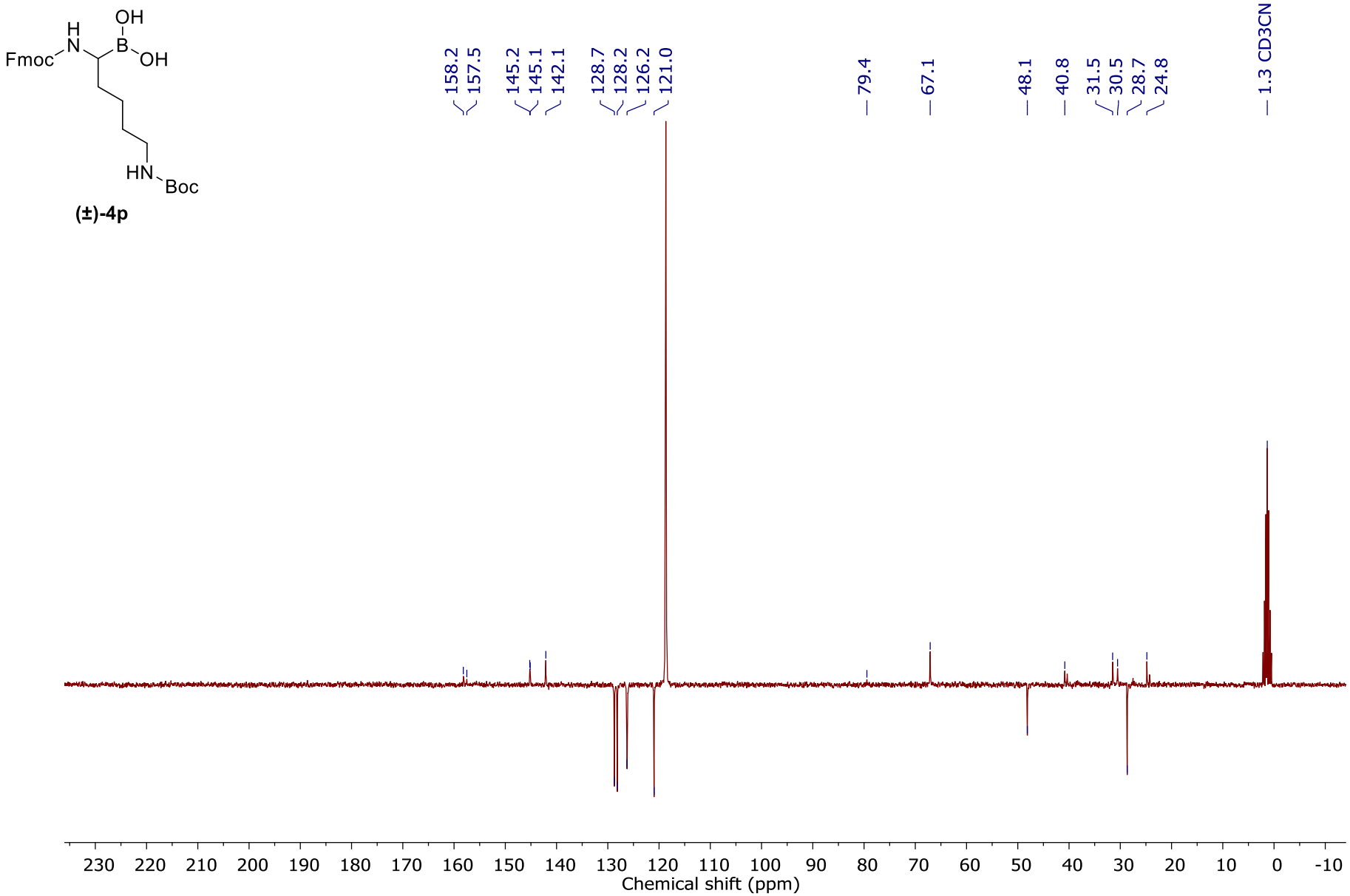

OH
H
N
B
OH
Fmoc
HN
Boc

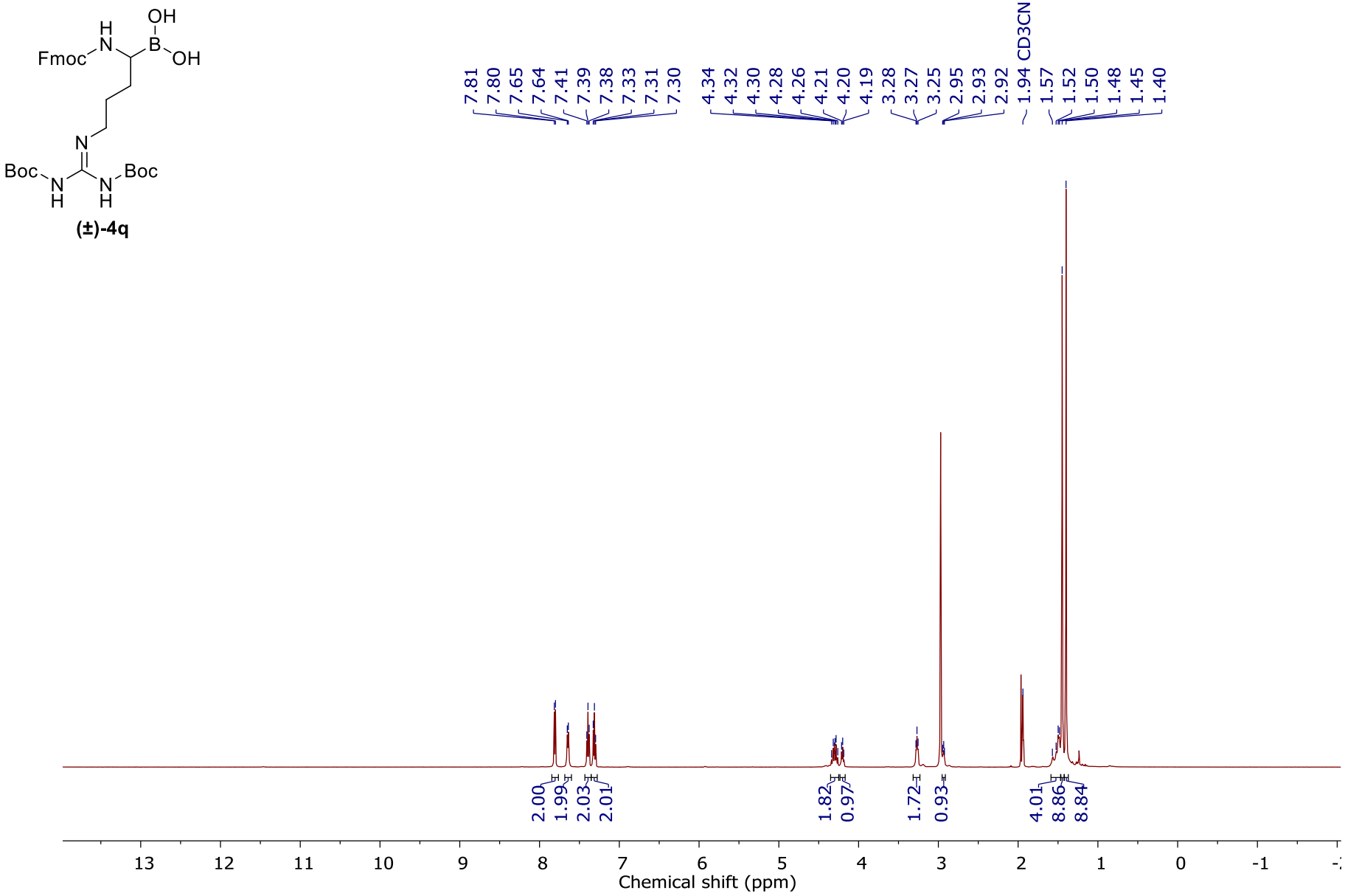
(±)-4o

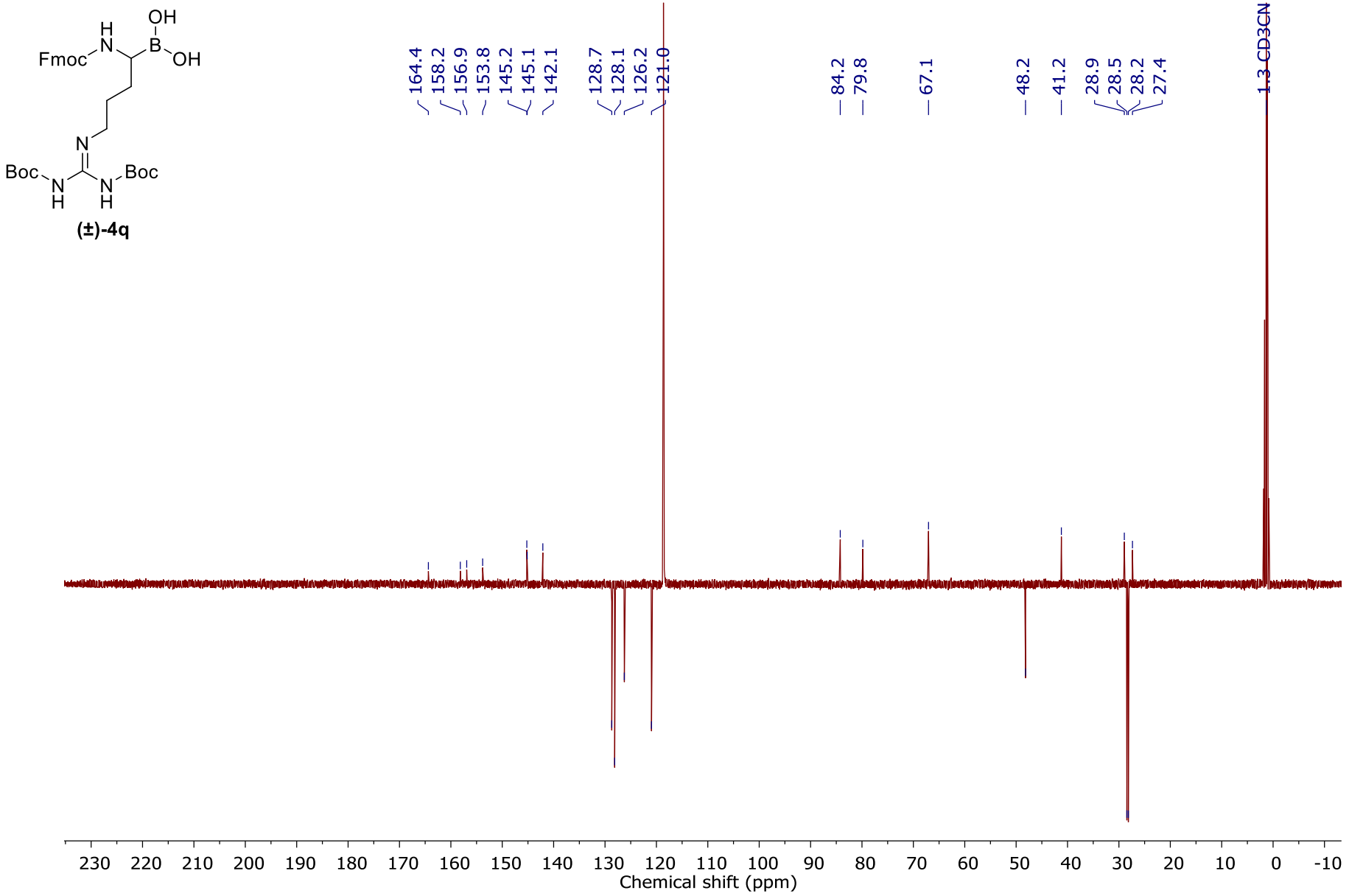
7.82
7.80
7.66
7.64
7.41
7.40
7.38
7.34
7.33
7.32
7.31
4.32
4.31
4.30
4.28
4.27
4.25
4.21
4.20
4.18
2.99
2.98
2.96
2.94
2.93
2.91
1.94 CD3CN
1.64
1.63
1.54
1.53
1.43
1.37
2.06
2.00
2.11
2.07
2.00
0.95
3.10
12.06
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

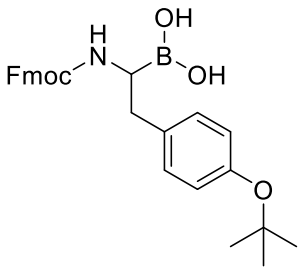

Fmoc
H
N
OH
B
OH
HN
Boc
(±)-4o
158.2
157.5
145.2
145.1
142.1
128.7
128.1
126.2
121.0
79.5
67.1
48.1
40.8
29.1
28.7
28.2
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)


OH
H
N
B
OH
Fmoc
HN
Boc
(±)-4p
7.82
7.81
7.66
7.66
7.65
7.64
7.42
7.40
7.39
7.34
7.32
7.31
4.31
4.29
4.27
4.21
4.20
4.19
2.96
2.95
2.90
2.86
1.94 CD3CN
1.61
1.57
1.51
1.44
1.36
1.29
1.26
1.23
2.00
1.94
2.04
2.06
1.85
0.94
3.02
4.00
8.75
2.22
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
HN
Boc
(±)-4p
158.2
157.5
145.2
145.1
142.1
128.7
128.2
126.2
121.0
79.4
67.1
48.1
40.8
31.5
30.5
28.7
24.8
1.3 CD3CN
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
Chemical shift (ppm)

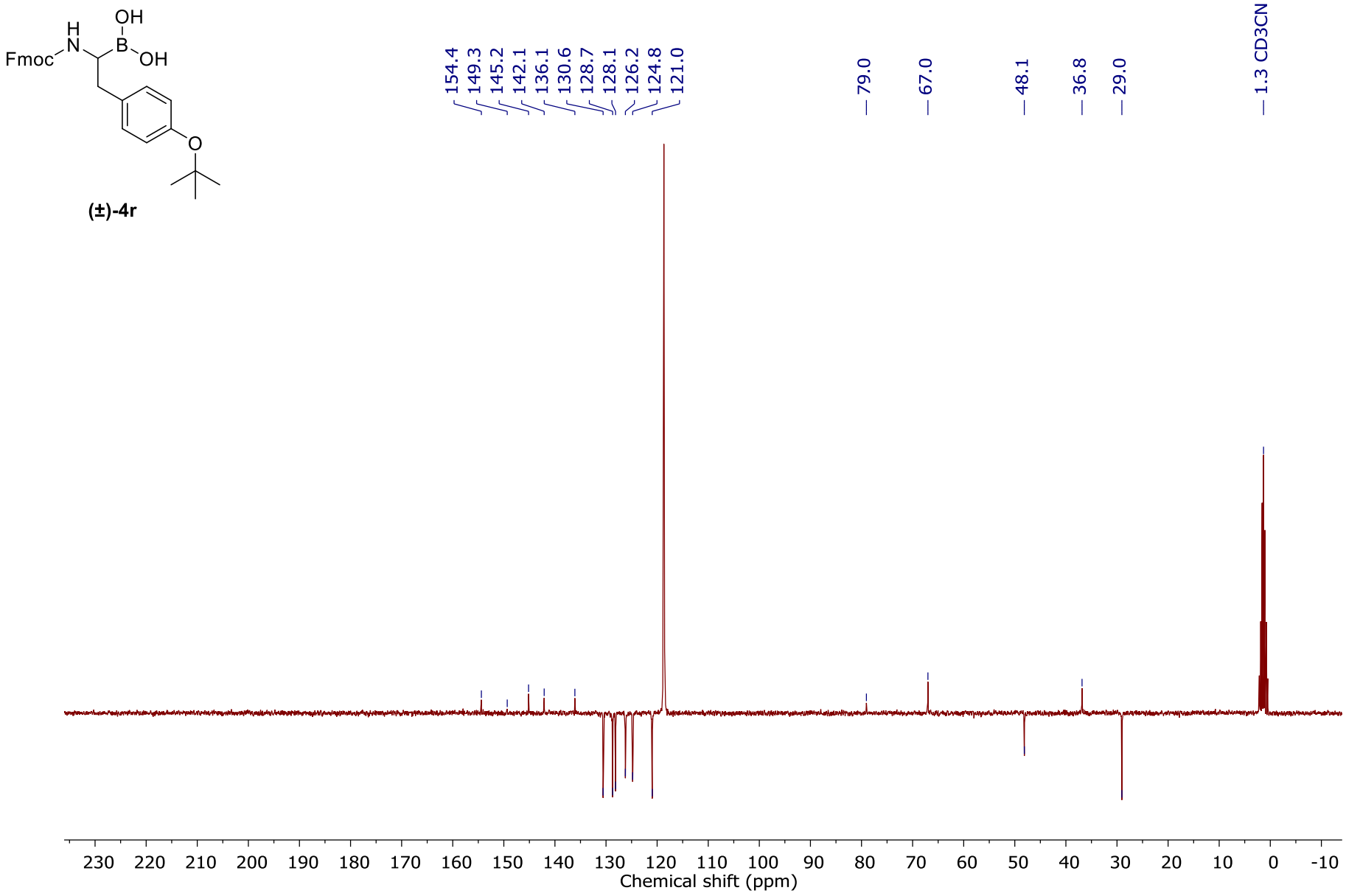

Fmoc
OH
B
OH
Boc
Boc
(±)-4q
7.81
7.80
7.65
7.64
7.41
7.39
7.38
7.33
7.31
7.30
4.34
4.32
4.30
4.28
4.26
4.21
4.20
4.19
3.28
3.27
3.25
2.95
2.93
2.92
1.94 CD3CN
1.57
1.52
1.50
1.48
1.45
1.40
2.00
1.99
2.03
2.01
1.82
0.97
1.72
0.93
4.01
8.86
8.84
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

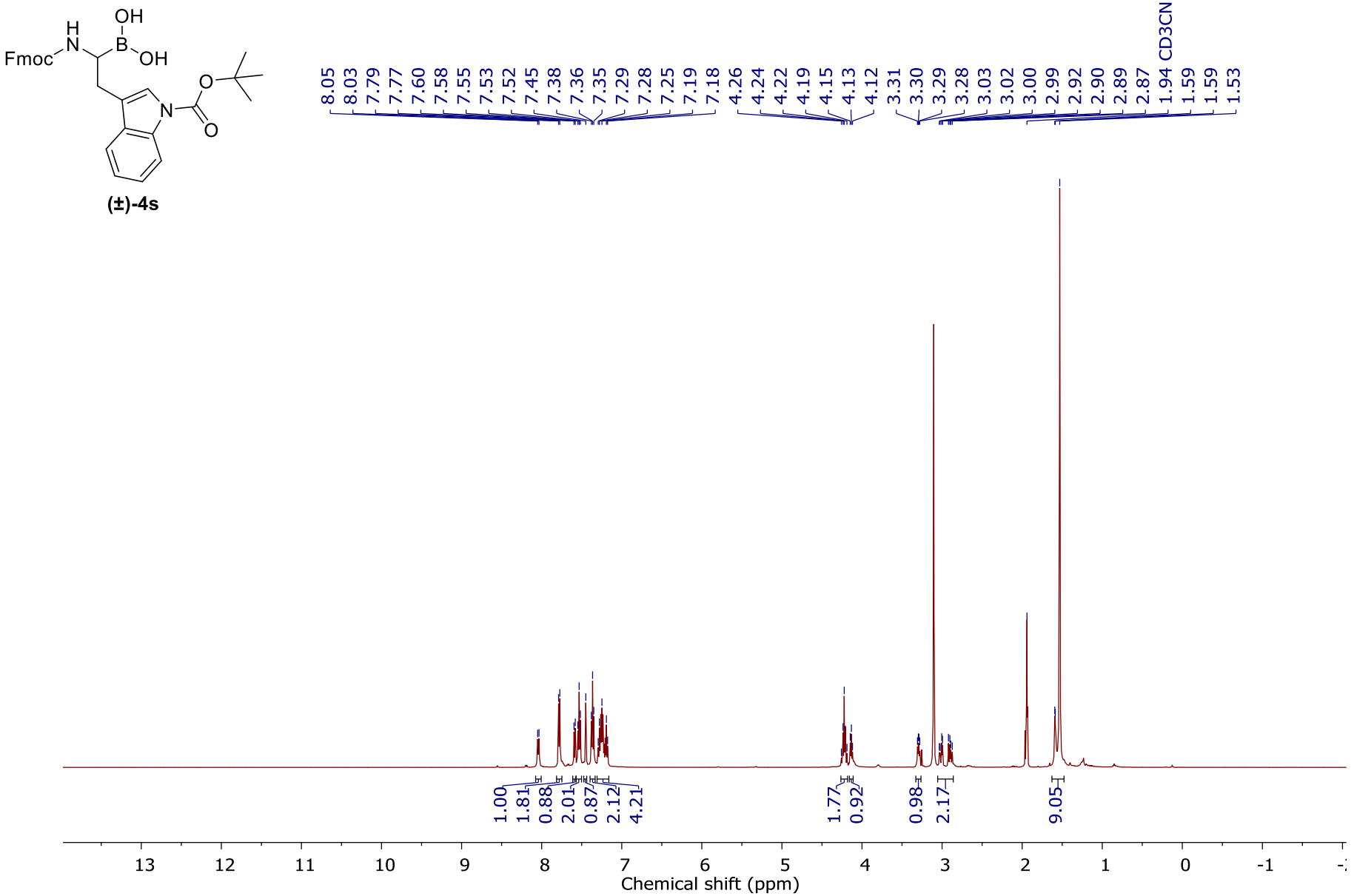

Fmoc
OH
B
OH
H
N
N
Boc
N
H
N
H
Boc
(±)-4q
164.4
158.2
156.9
153.8
145.2
145.1
142.1
128.7
128.1
126.2
121.0
84.2
79.8
67.1
48.2
41.2
28.9
28.5
28.2
27.4
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

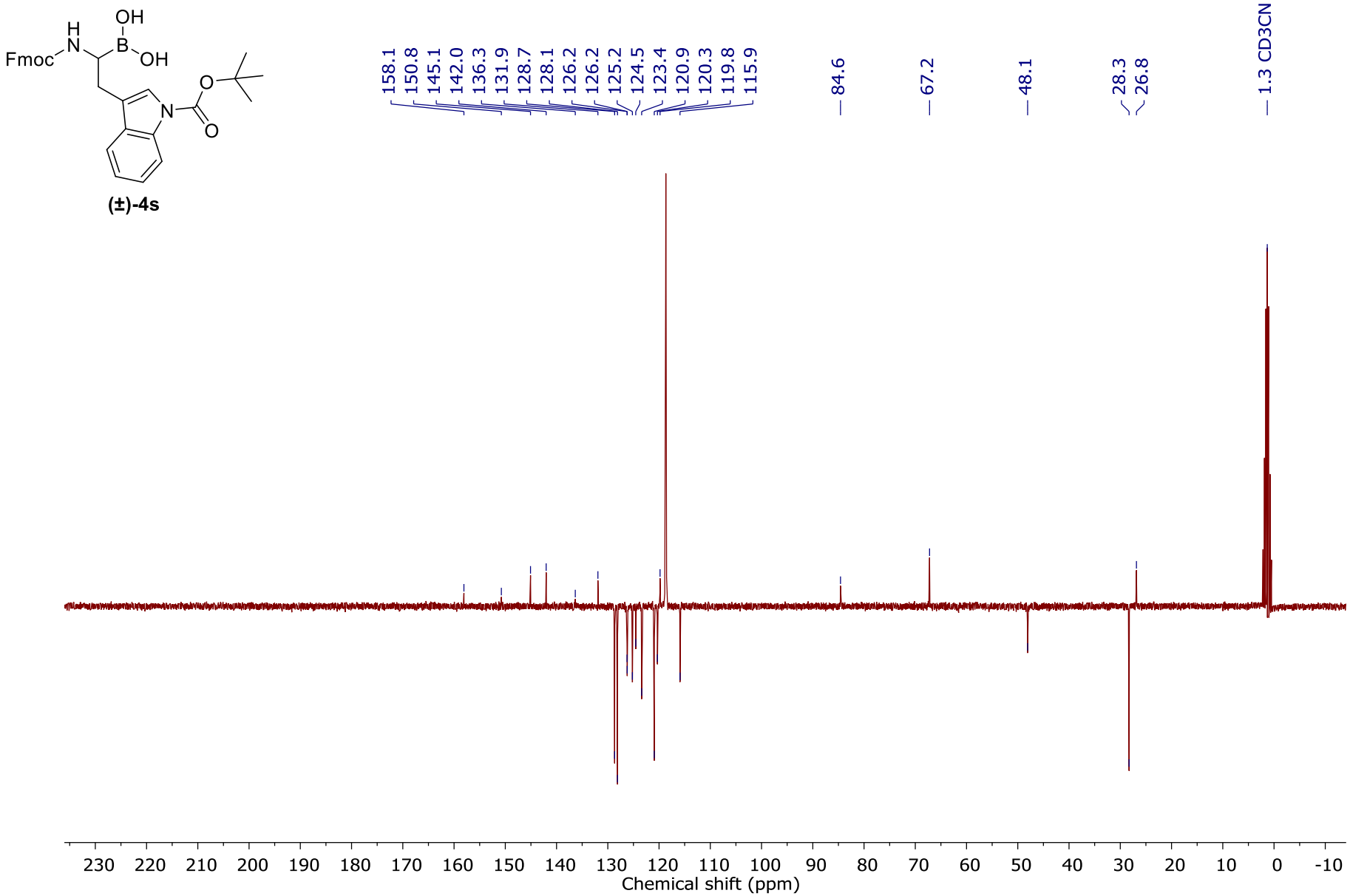

OH
H
N
B
OH
Fmoc
O

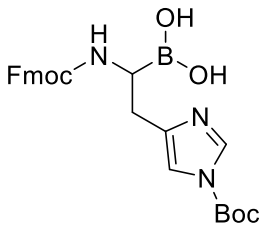
(±)-4r

7.83
7.80
7.62
7.60
7.43
7.40
7.38
7.34
7.32
7.29
7.02
6.99
6.82
6.79
4.29
4.28
4.27
4.25
4.21
4.17
4.14
4.12
3.15
3.13
3.12
3.10
2.87
2.82
2.80
2.71
2.68
2.66
2.63
1.94 CD3CN
1.22
2.00
2.04
2.25
2.07
1.76
1.96
1.99
1.06
0.84
2.24
9.23
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
O
(±)-4r
154.4
149.3
145.2
142.1
136.1
130.6
128.7
128.1
126.2
124.8
121.0
79.0
67.0
48.1
36.8
29.0
1.3 CD3CN
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
Chemical shift (ppm)

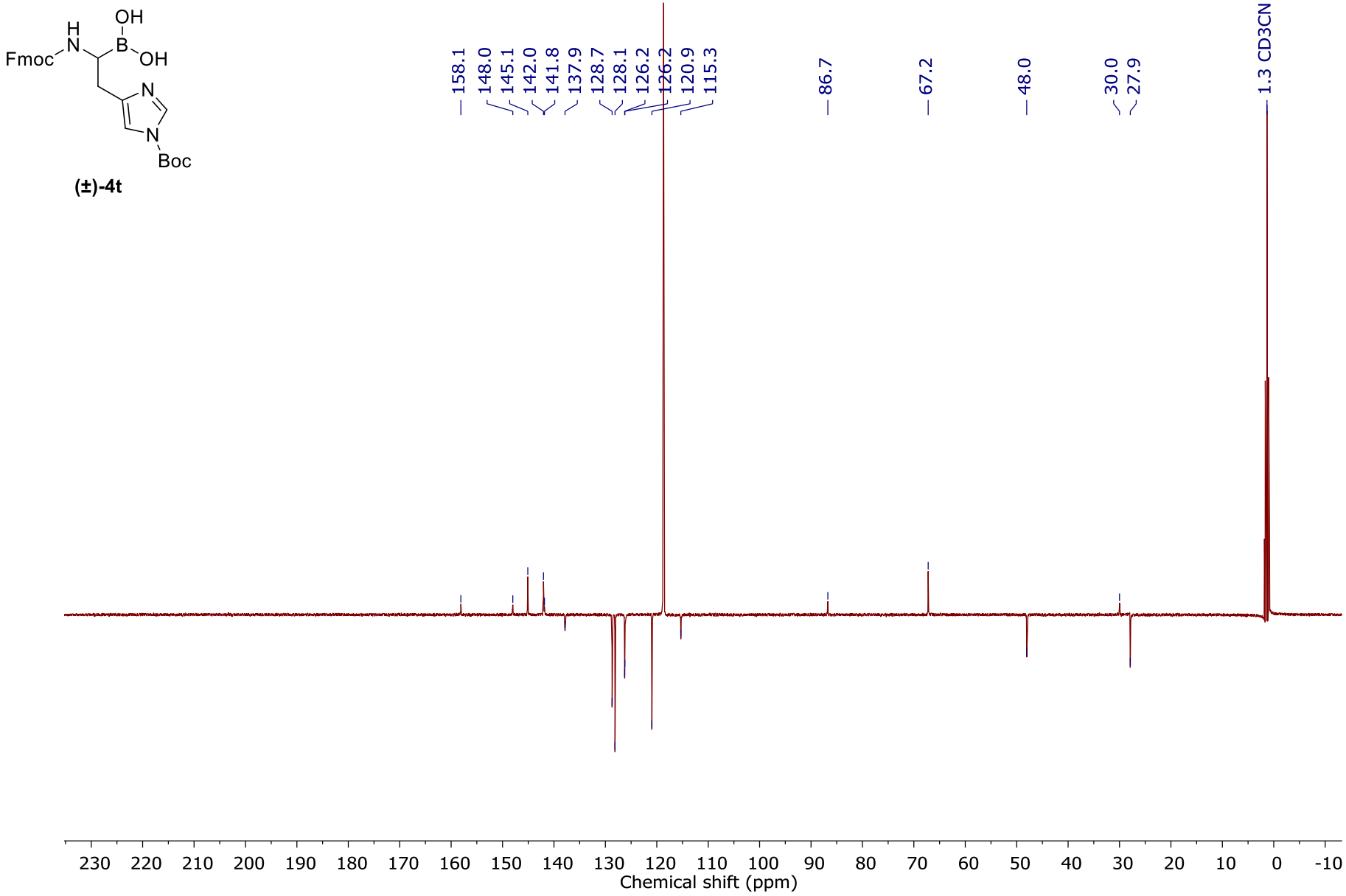

Fmoc
H
N
OH
B
OH
O
O
N
O
(±)-4s
8.05
8.03
7.79
7.77
7.60
7.58
7.55
7.53
7.52
7.45
7.38
7.36
7.35
7.29
7.28
7.25
7.19
7.18
4.26
4.24
4.22
4.19
4.15
4.13
4.12
3.31
3.30
3.29
3.28
3.03
3.02
3.00
2.99
2.92
2.90
2.89
2.87
1.94 CD3CN
1.59
1.59
1.53
1.00
1.81
0.88
2.01
0.87
2.12
4.21
1.77
0.92
0.98
2.17
9.05
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
O
O
N
O
(±)-4s
158.1
150.8
145.1
142.0
136.3
131.9
128.7
128.1
126.2
126.2
125.2
124.5
123.4
120.9
120.3
119.8
115.9
84.6
67.2
48.1
28.3
26.8
1.3 CD3CN
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
Chemical shift (ppm)

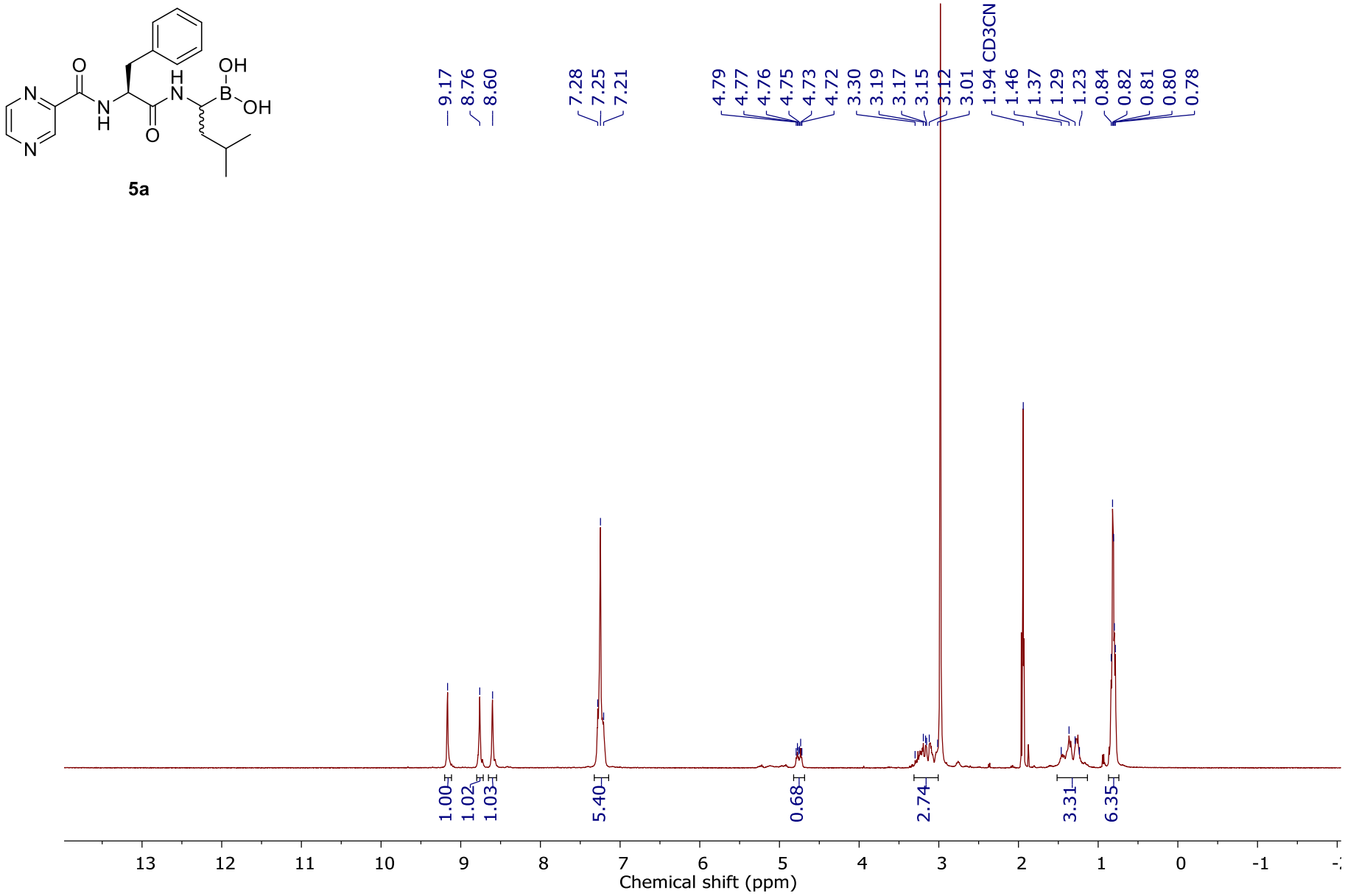

OH
H
N
B
OH
Fmoc
N
N
Boc

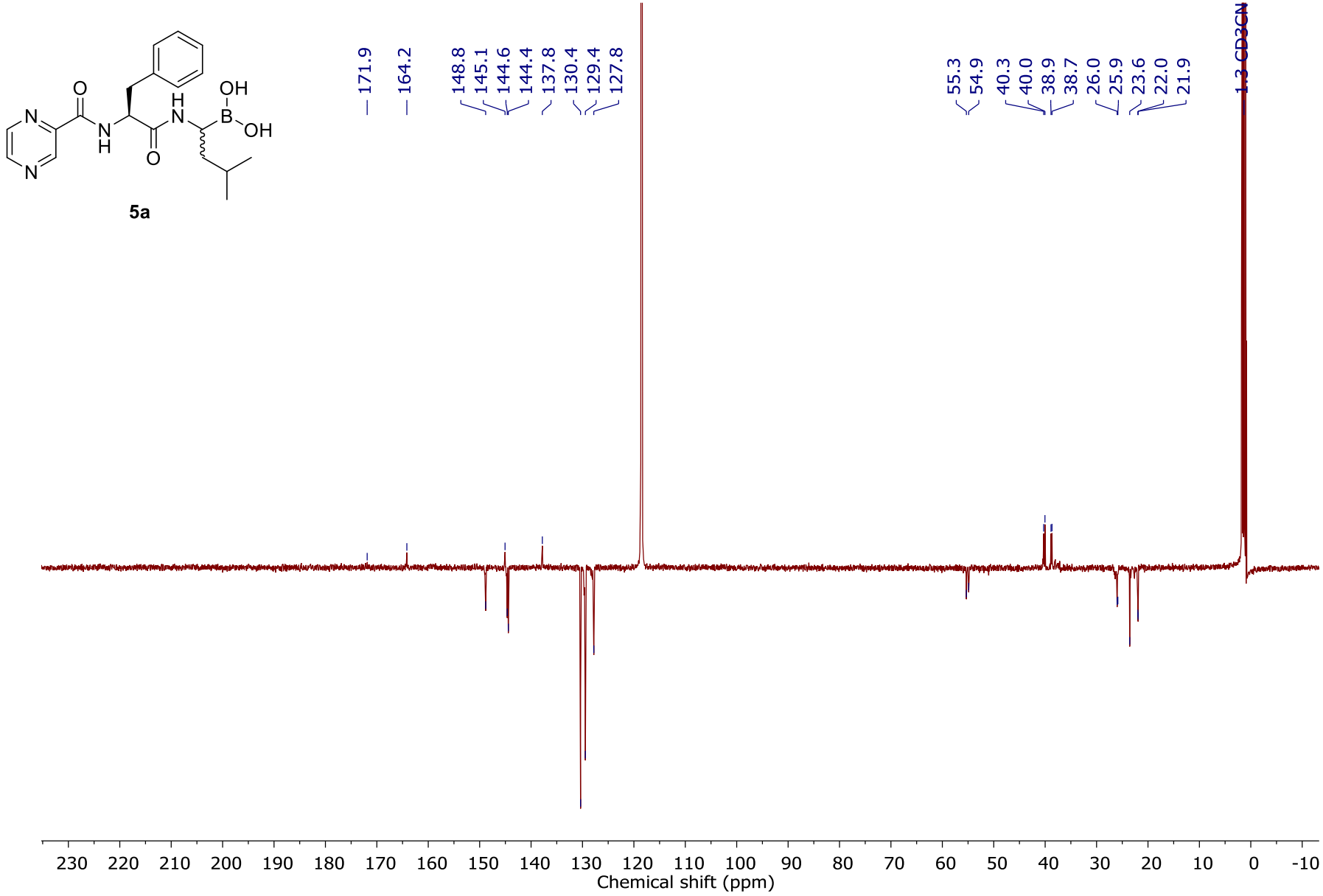
(±)-4t

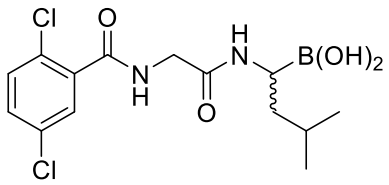
8.05
7.80
7.78
7.58
7.57
7.39
7.38
7.36
7.30
7.29
7.27
7.19
4.26
4.24
4.23
4.18
4.14
4.13
4.12
3.19
3.18
3.17
2.82
2.79
2.78
2.73
2.72
2.69
1.94 CD3CN
1.47
0.85
1.63
1.66
1.78
2.01
0.95
1.72
0.97
1.05
2.00
9.24
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Fmoc
H
N
OH
B
OH
N
N
Boc
(±)-4t
158.1
148.0
145.1
142.0
141.8
137.9
128.7
128.1
126.2
126.2
120.9
115.3
86.7
67.2
48.0
30.0
27.9
1.3 CD3CN
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
Chemical shift (ppm)

NMR spectra of peptide-boronic acids

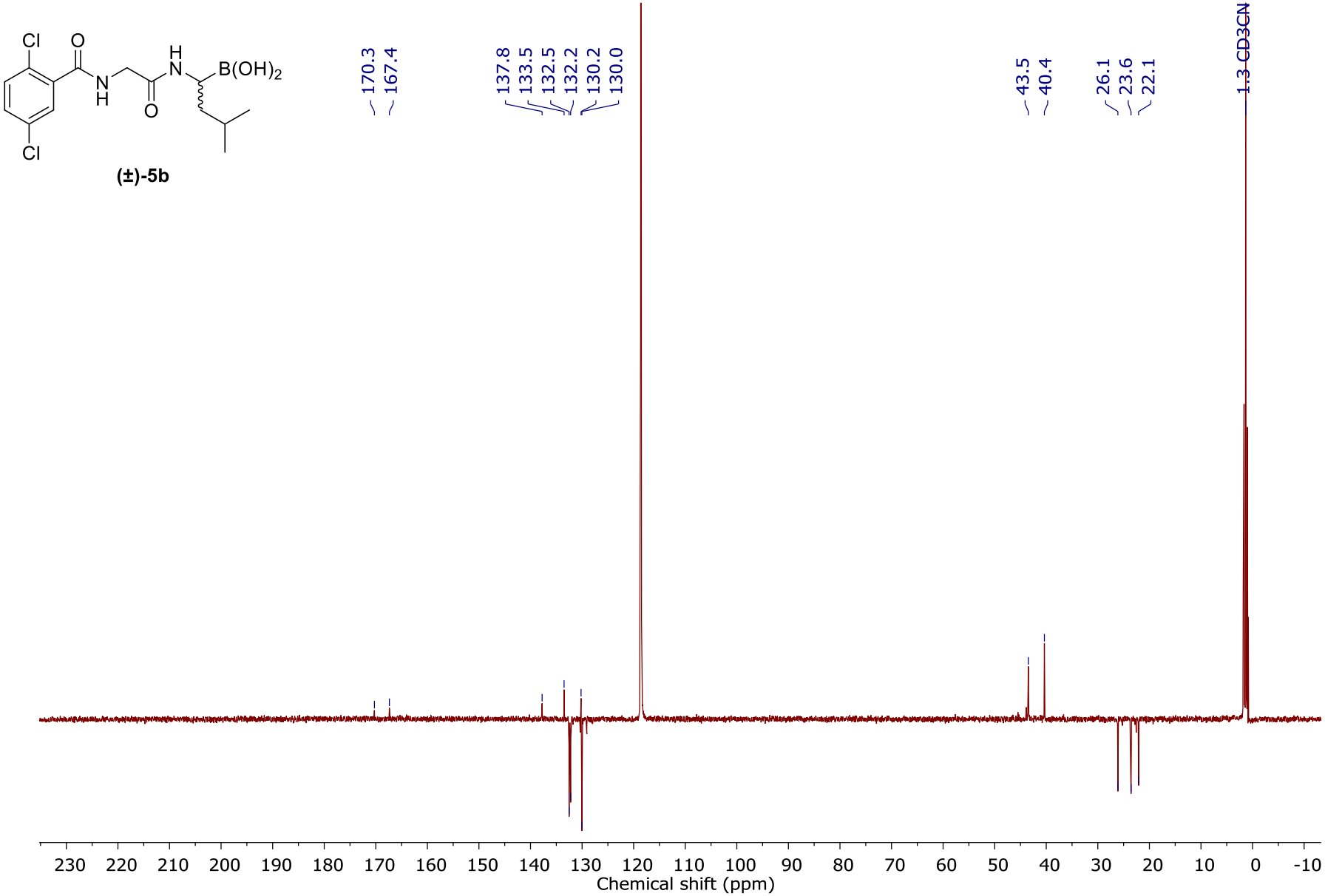

5a
9.17
8.76
8.60
7.28
7.25
7.21
4.79
4.77
4.76
4.75
4.73
4.72
3.30
3.19
3.17
3.15
3.12
3.01
1.94 CD3CN
1.46
1.37
1.29
1.23
0.84
0.82
0.81
0.80
0.78
1.00
1.02
1.03
5.40
0.68
2.74
3.31
6.35
Chemical shift (ppm)

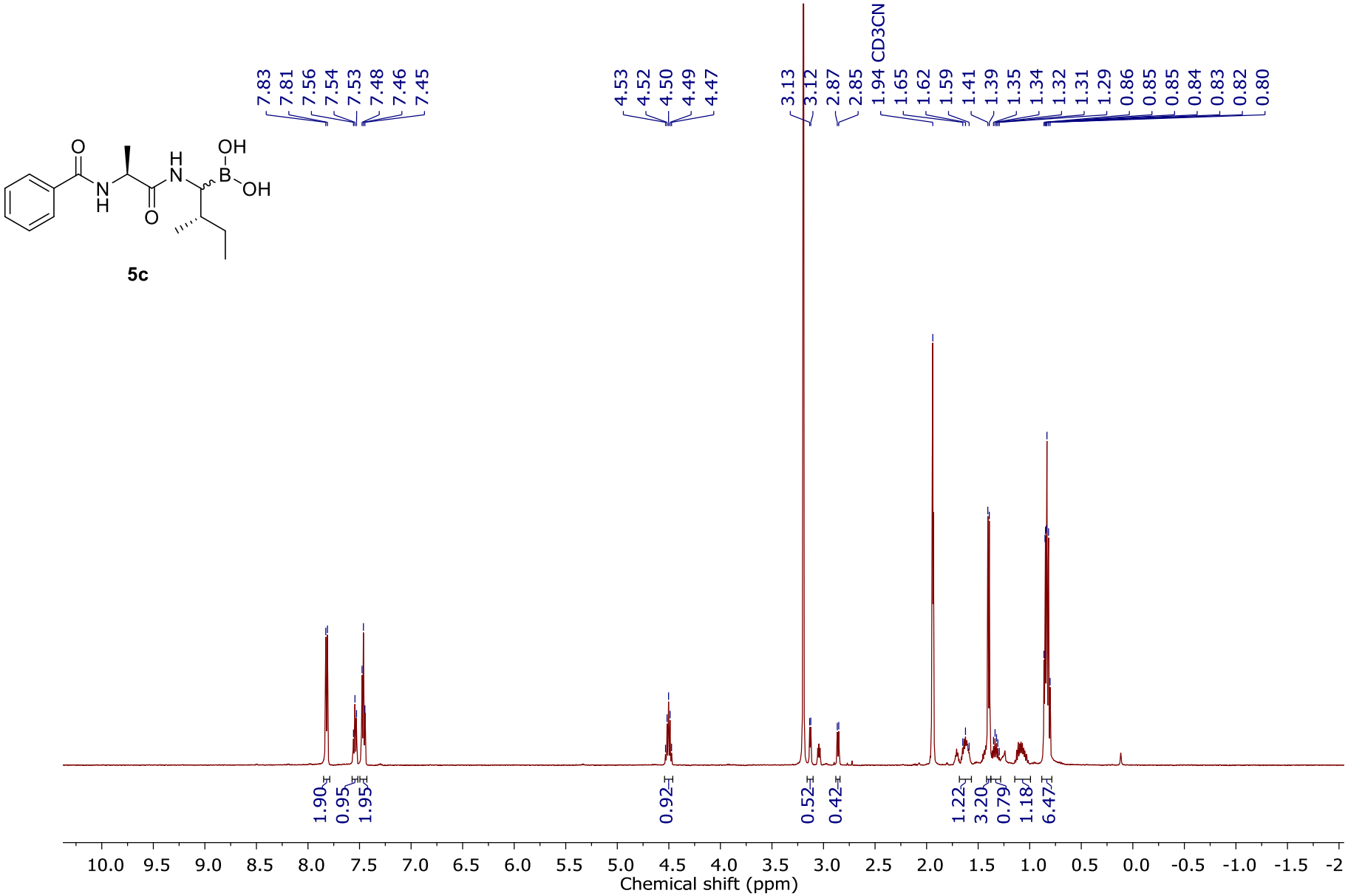

5a
171.9
164.2
148.8
145.1
144.6
144.4
137.8
130.4
129.4
127.8
55.3
54.9
40.3
40.0
38.9
38.7
26.0
25.9
23.6
22.0
21.9
1.3 CD3CN
Chemical shift (ppm)


Cl
O
N
H
H
N
B(OH)2
O
Cl

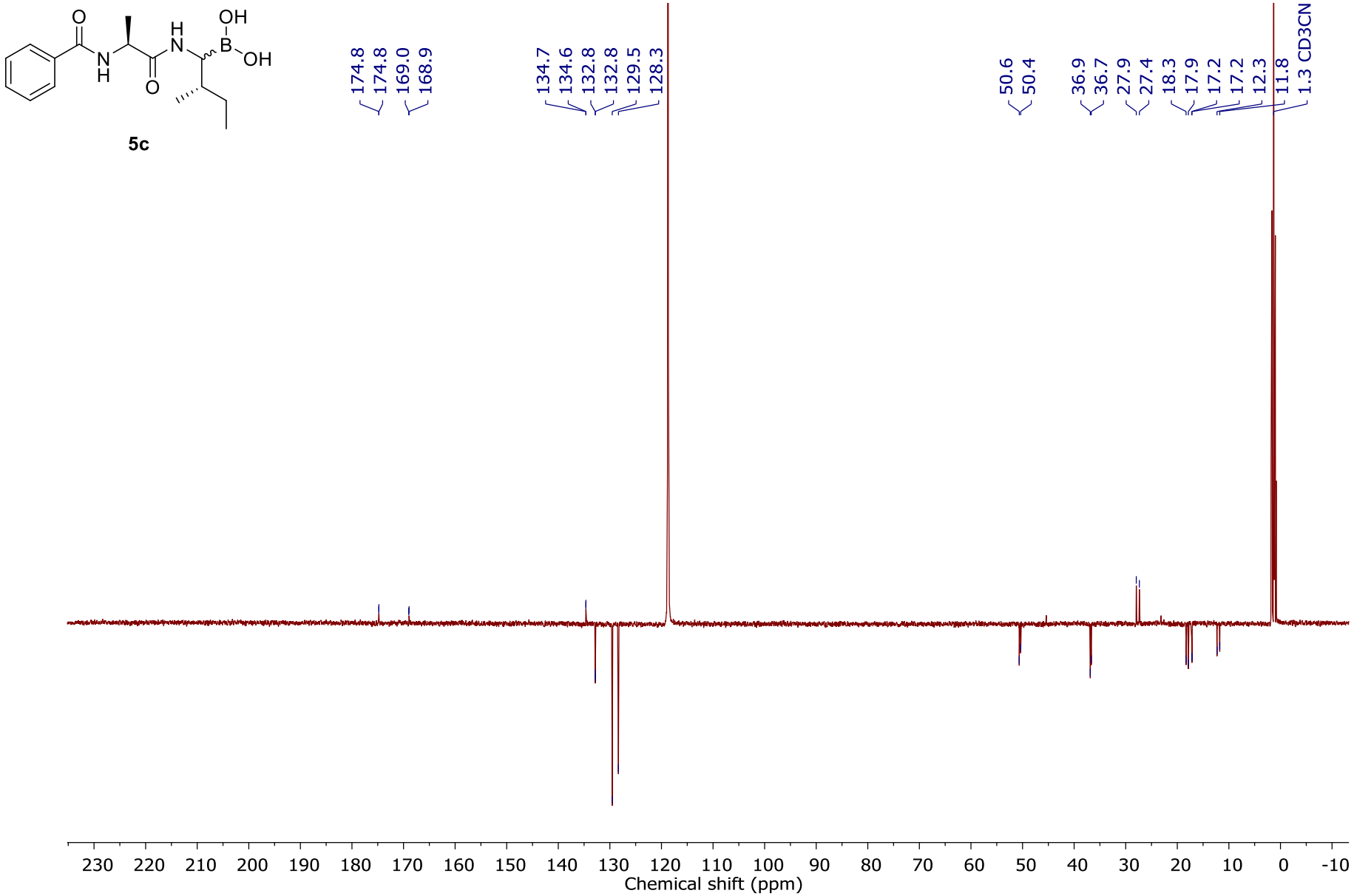
(±)-5b

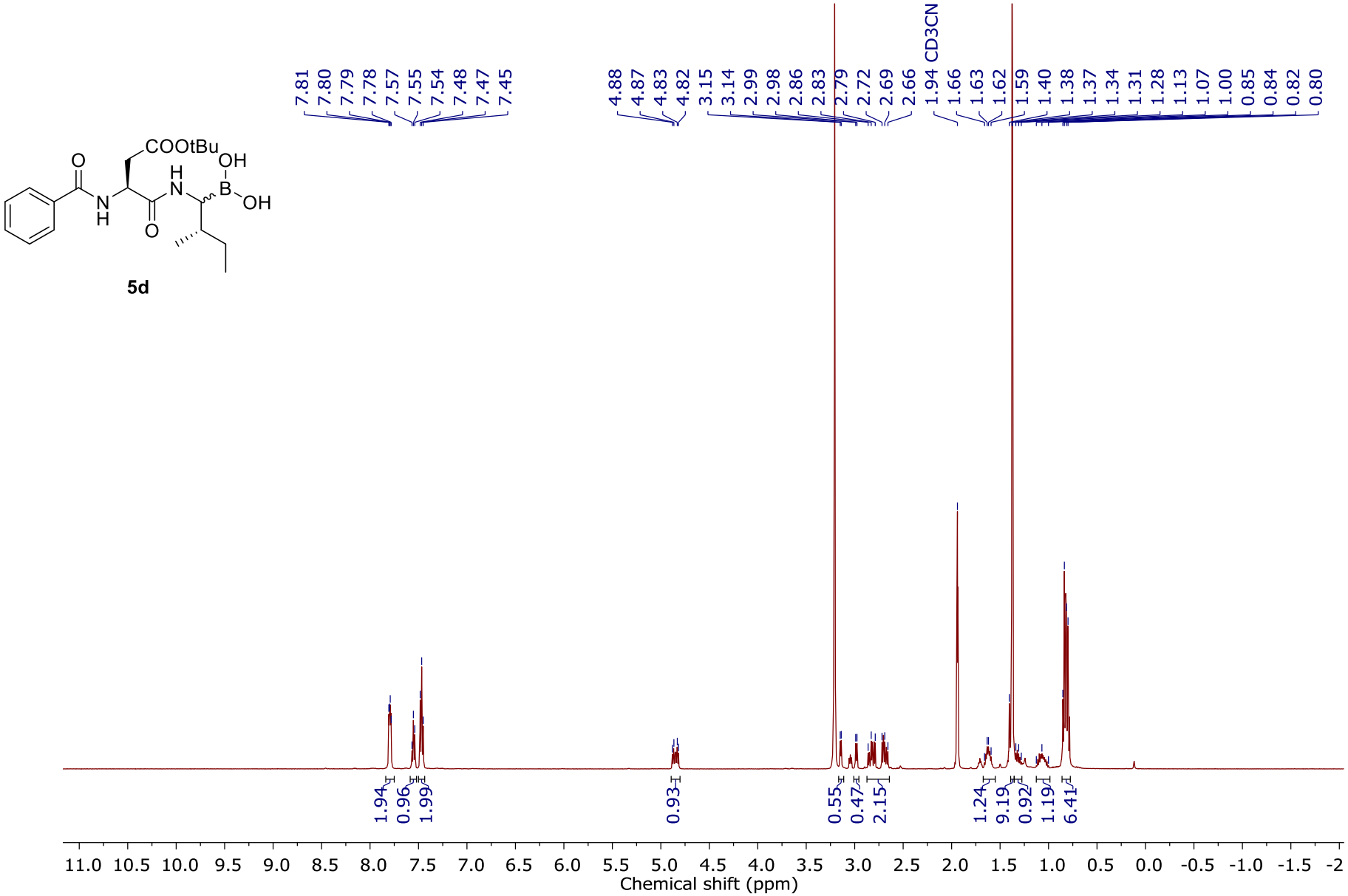
7.55
7.45
3.94
3.08
3.07
3.06
3.05
1.94 CD3CN
1.63
1.60
1.56
1.48
1.45
1.42
1.37
1.33
1.30
0.88
0.87
0.87
0.85
0.98
1.95
1.79
0.89
1.00
0.97
1.18
6.25
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


Cl
O
N
H
H
N
B(OH)2
O
Cl
(±)-5b
170.3
167.4
137.8
133.5
132.5
132.2
130.2
130.0
43.5
40.4
26.1
23.6
22.1
1.3 CD3CN
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
Chemical shift (ppm)

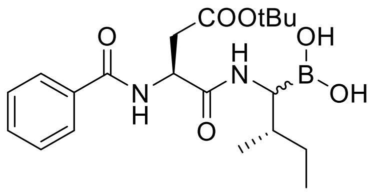

7.83
7.81
7.56
7.54
7.53
7.48
7.46
7.45
4.53
4.52
4.50
4.49
4.47
3.13
3.12
2.87
2.85
1.94 CD3CN
1.65
1.62
1.59
1.41
1.39
1.35
1.34
1.32
1.31
1.29
0.86
0.85
0.85
0.84
0.83
0.82
0.80
1.90
0.95
1.95
0.92
0.52
0.42
1.22
3.20
0.79
1.18
6.47
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5 -2
Chemical shift (ppm)

5c

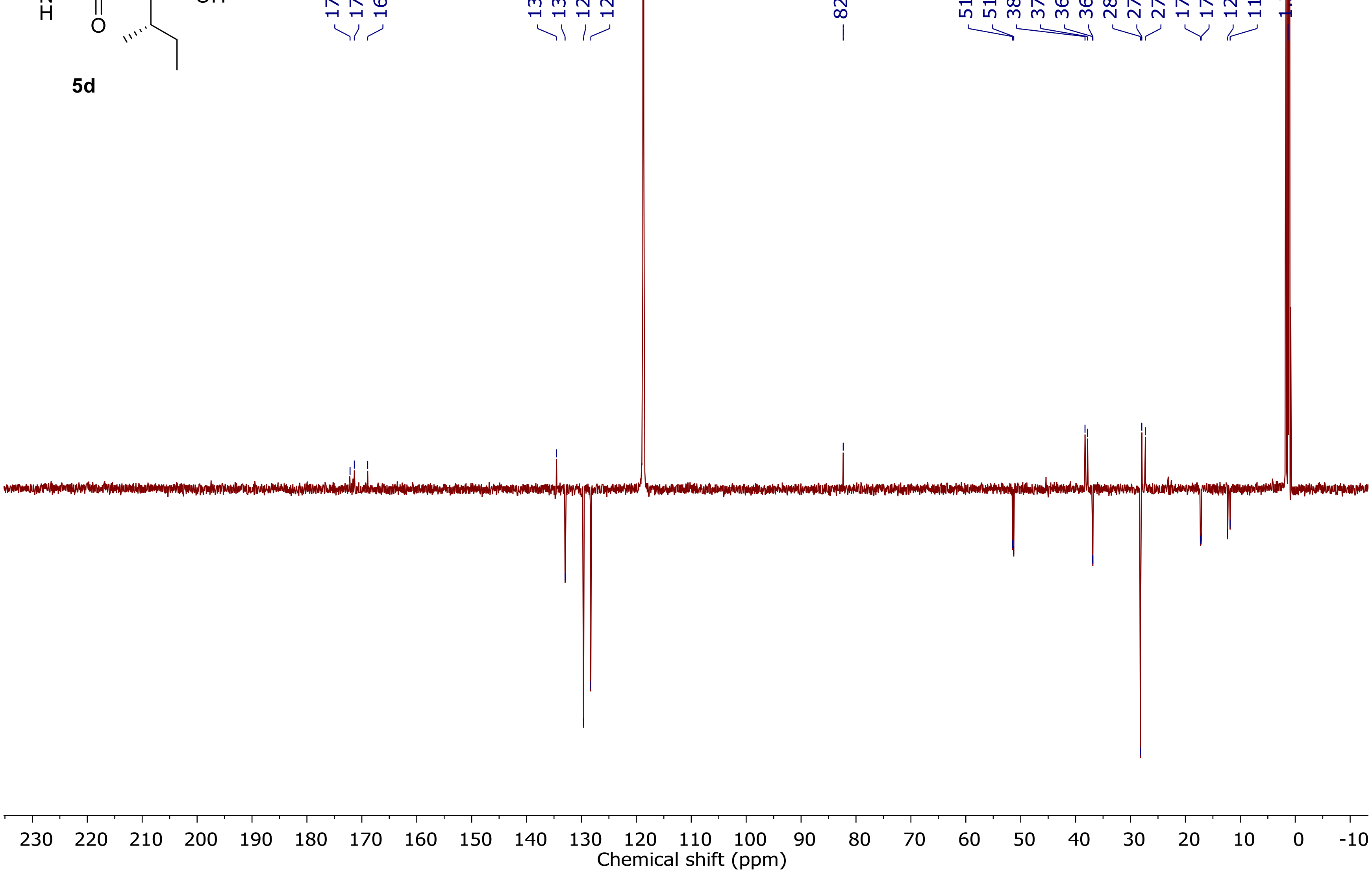

O
N
H
O
H
N
OH
B
OH
5c
174.8
174.8
169.0
168.9
134.7
134.6
132.8
132.8
129.5
128.3
50.6
50.4
36.9
36.7
27.9
27.4
18.3
17.9
17.2
17.2
12.3
11.8
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

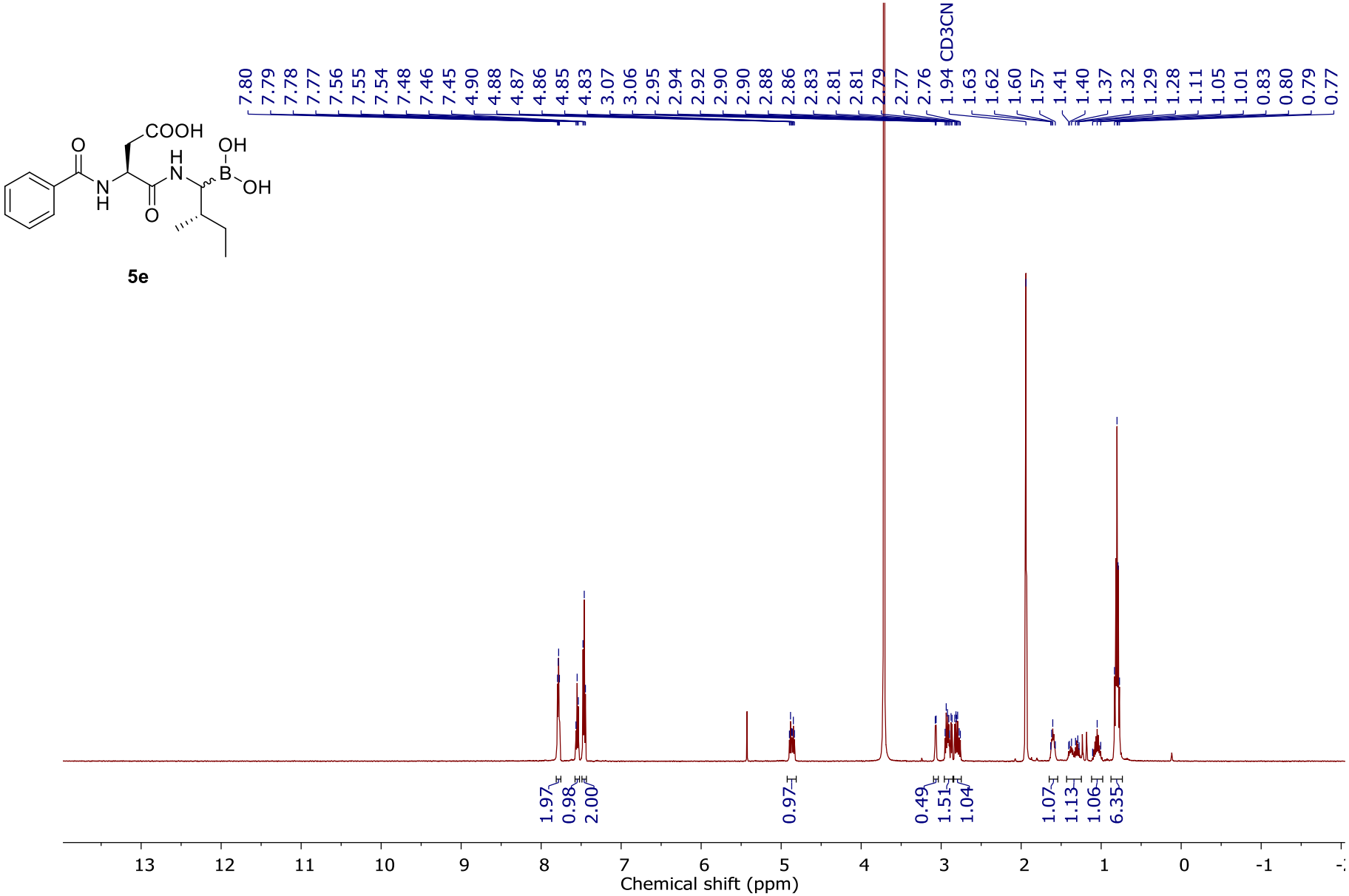

7.81
7.80
7.79
7.78
7.57
7.55
7.54
7.48
7.47
7.45
4.88
4.87
4.83
4.82
3.15
3.14
2.99
2.98
2.86
2.83
2.79
2.72
2.69
2.66
1.94 CD3CN
1.66
1.63
1.62
1.59
1.40
1.38
1.37
1.34
1.31
1.28
1.13
1.07
1.00
0.85
0.84
0.82
0.80
1.94
0.96
1.99
0.93
0.55
0.47
2.15
1.24
9.19
0.92
1.19
6.41
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1.5 -2
Chemical shift (ppm)

5d

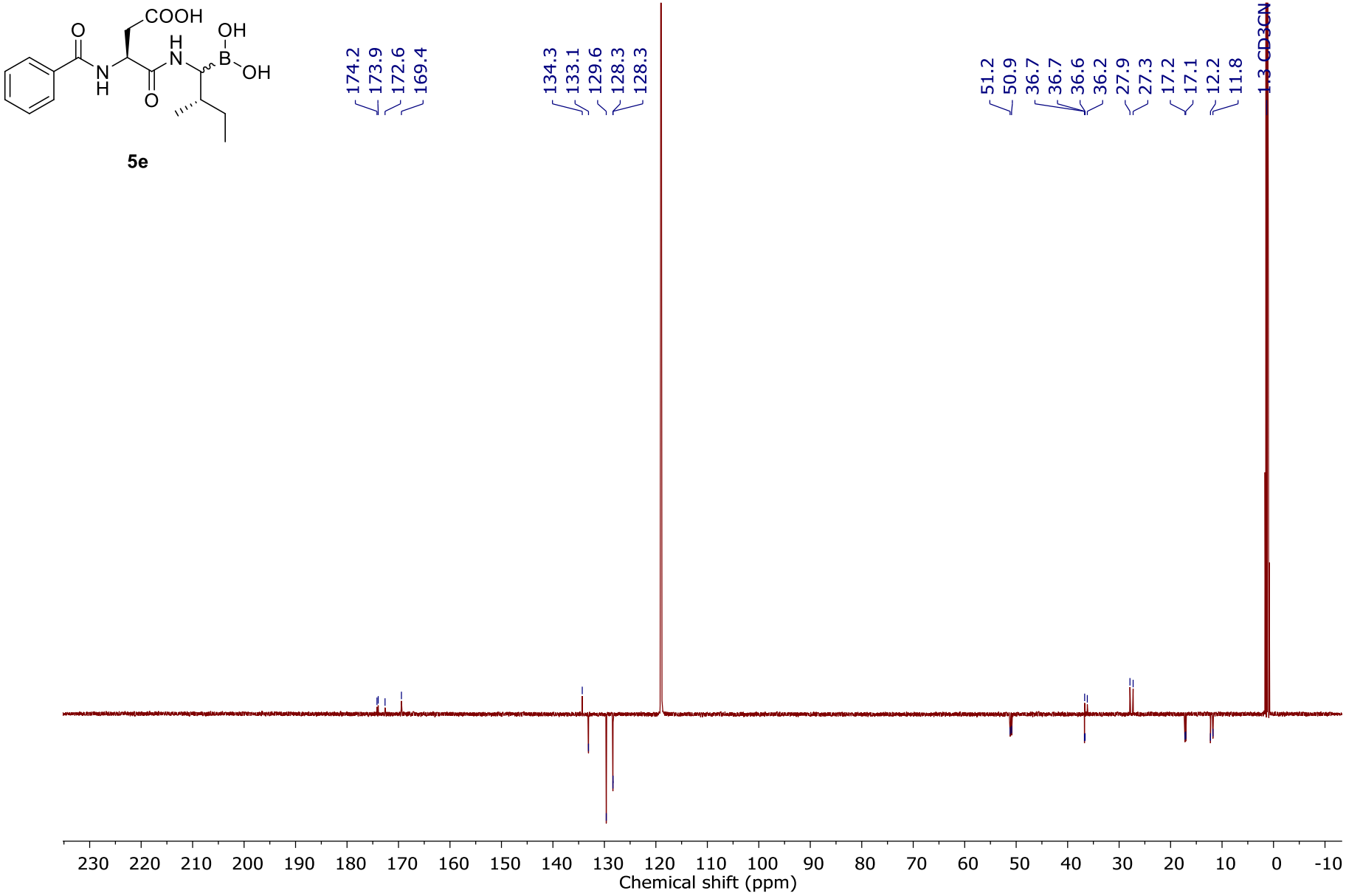

COOtBu
OH
O
H
N
B
OH
N
H
O

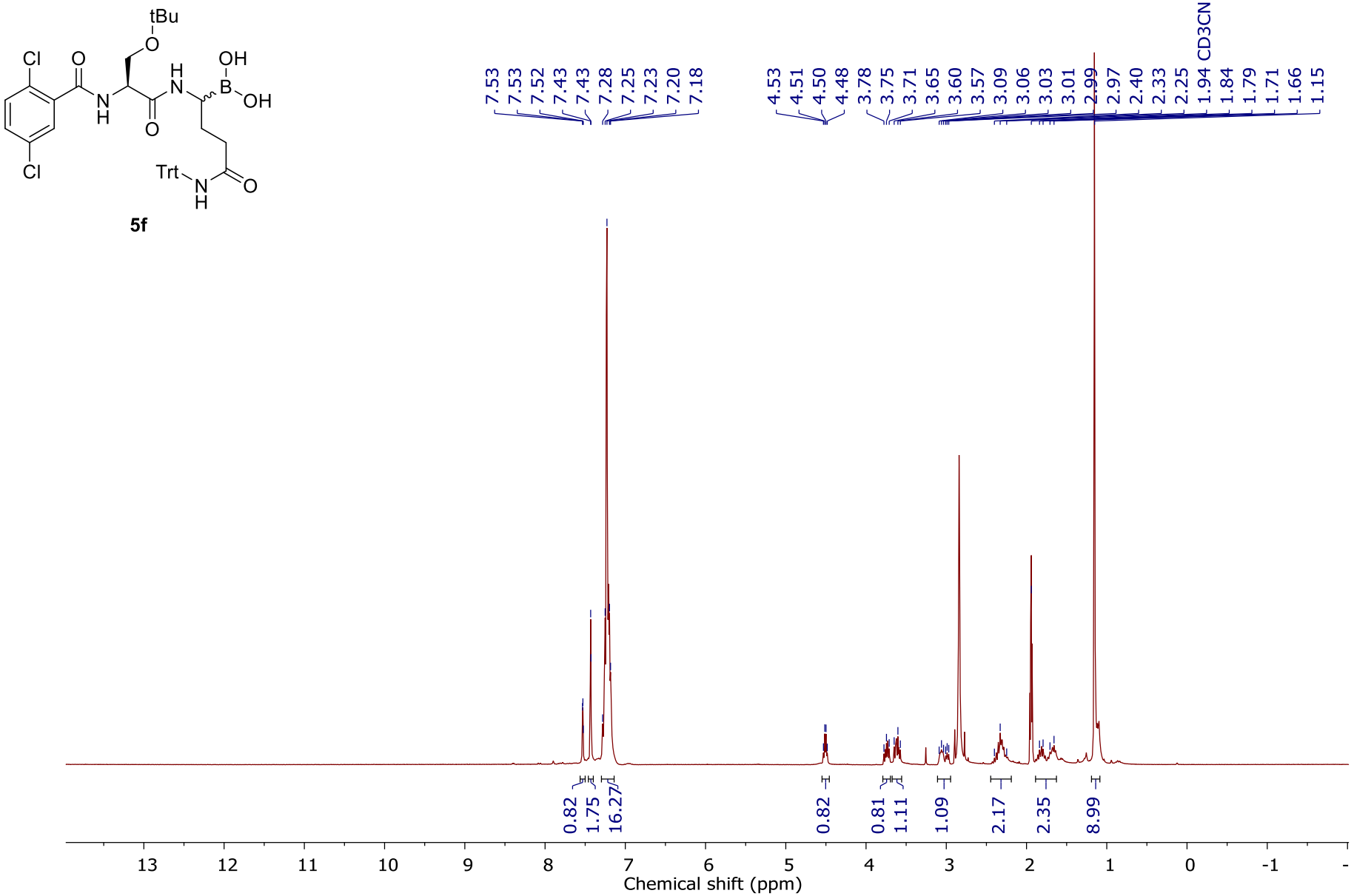
5d

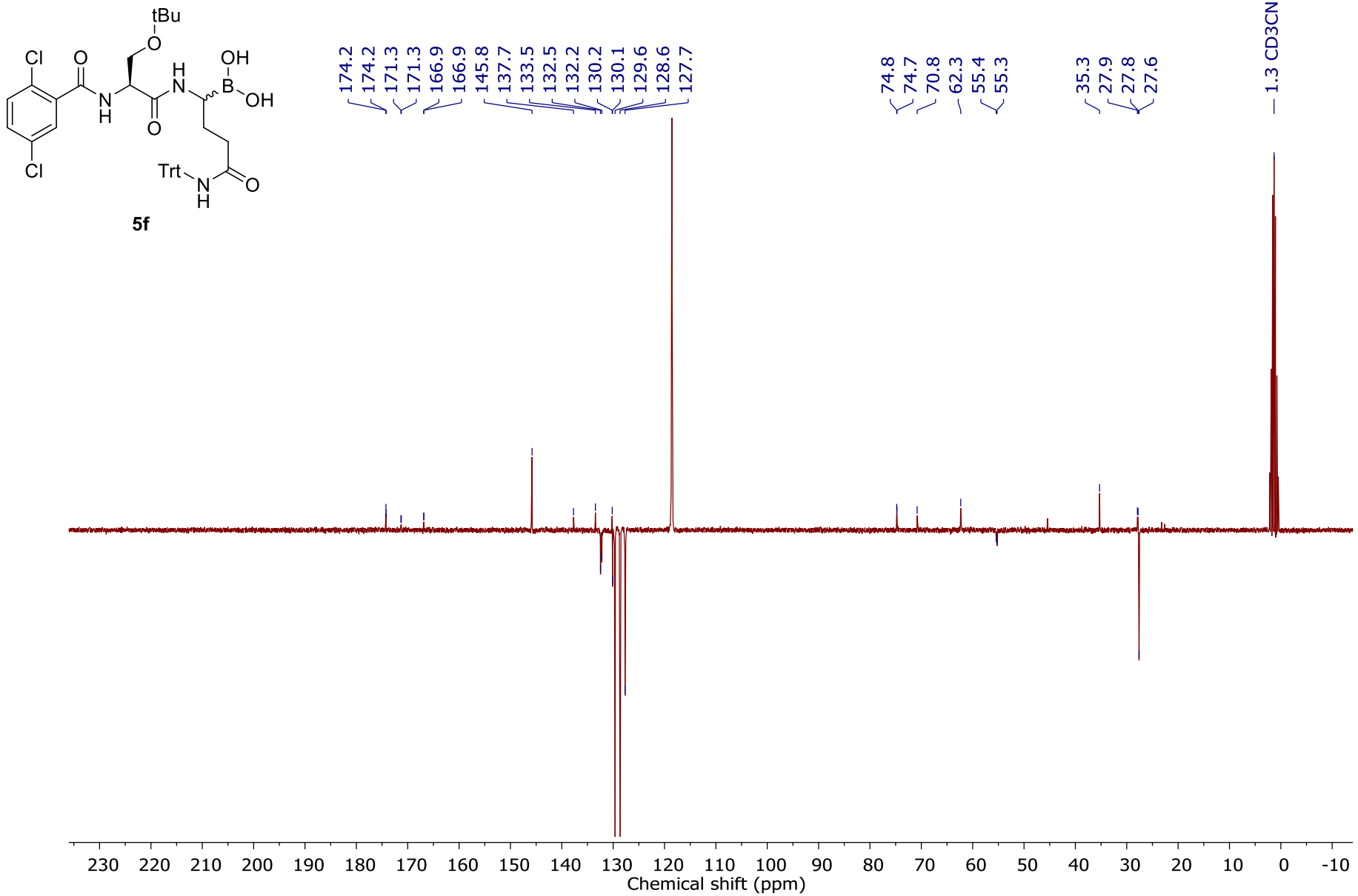

172.1
171.4
168.9
134.5
133.0
129.6
128.3
82.3
51.5
51.3
38.3
37.8
36.9
36.9
28.2
27.9
27.3
17.3
17.1
12.3
11.9
1.3 CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

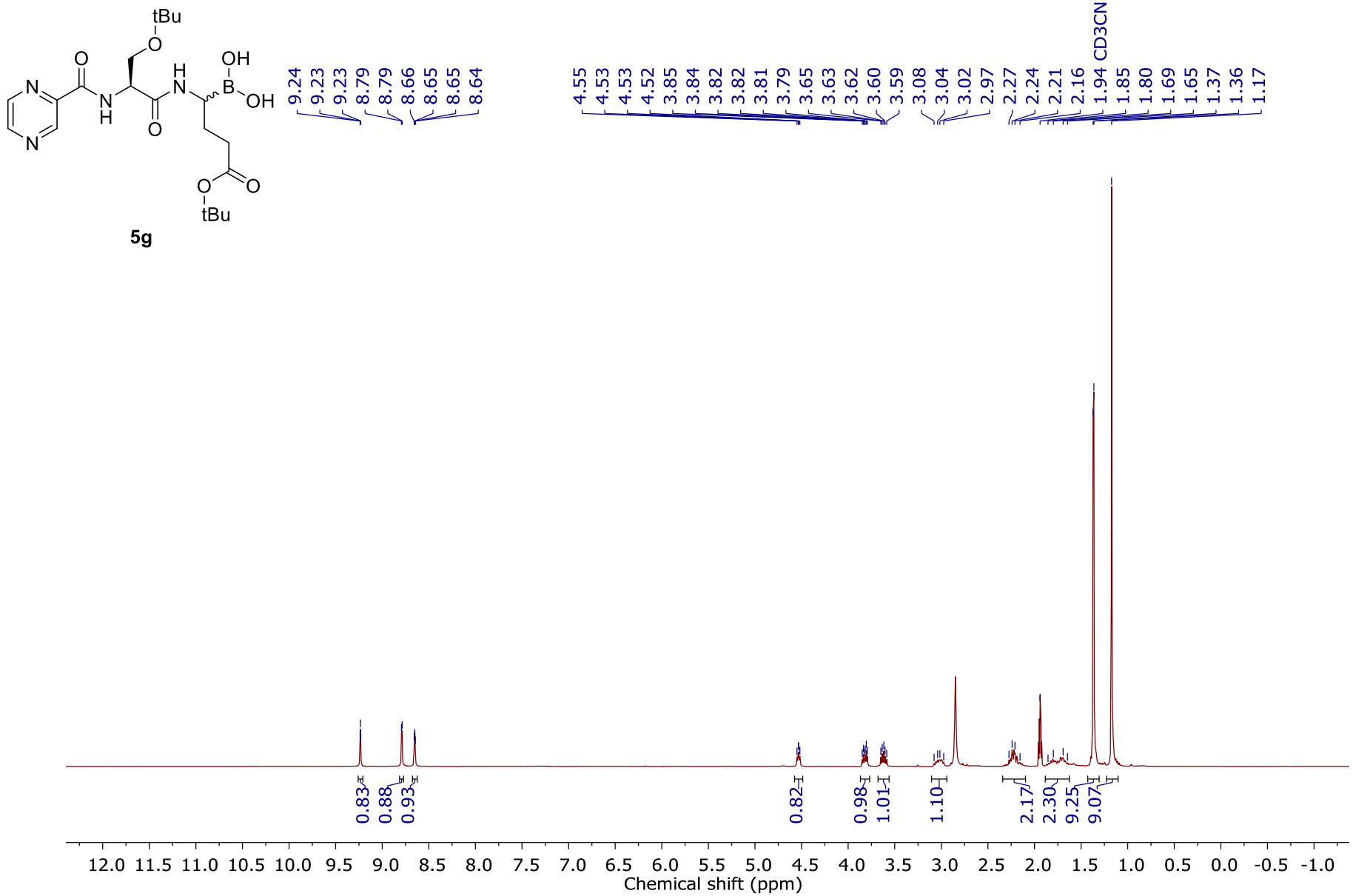

7.80
7.79
7.78
7.77
7.56
7.55
7.54
7.48
7.46
7.45
4.90
4.88
4.87
4.86
4.85
4.83
3.07
3.06
2.95
2.94
2.92
2.90
2.90
2.88
2.86
2.83
2.81
2.81
2.79
2.77
2.76
1.94 CD3CN
1.63
1.62
1.60
1.57
1.41
1.40
1.37
1.32
1.29
1.28
1.11
1.05
1.01
0.83
0.80
0.79
0.77
COOH
OH
OH
1.97
0.98
2.00
0.97
0.49
1.51
1.04
1.07
1.13
1.06
6.35
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)

5e

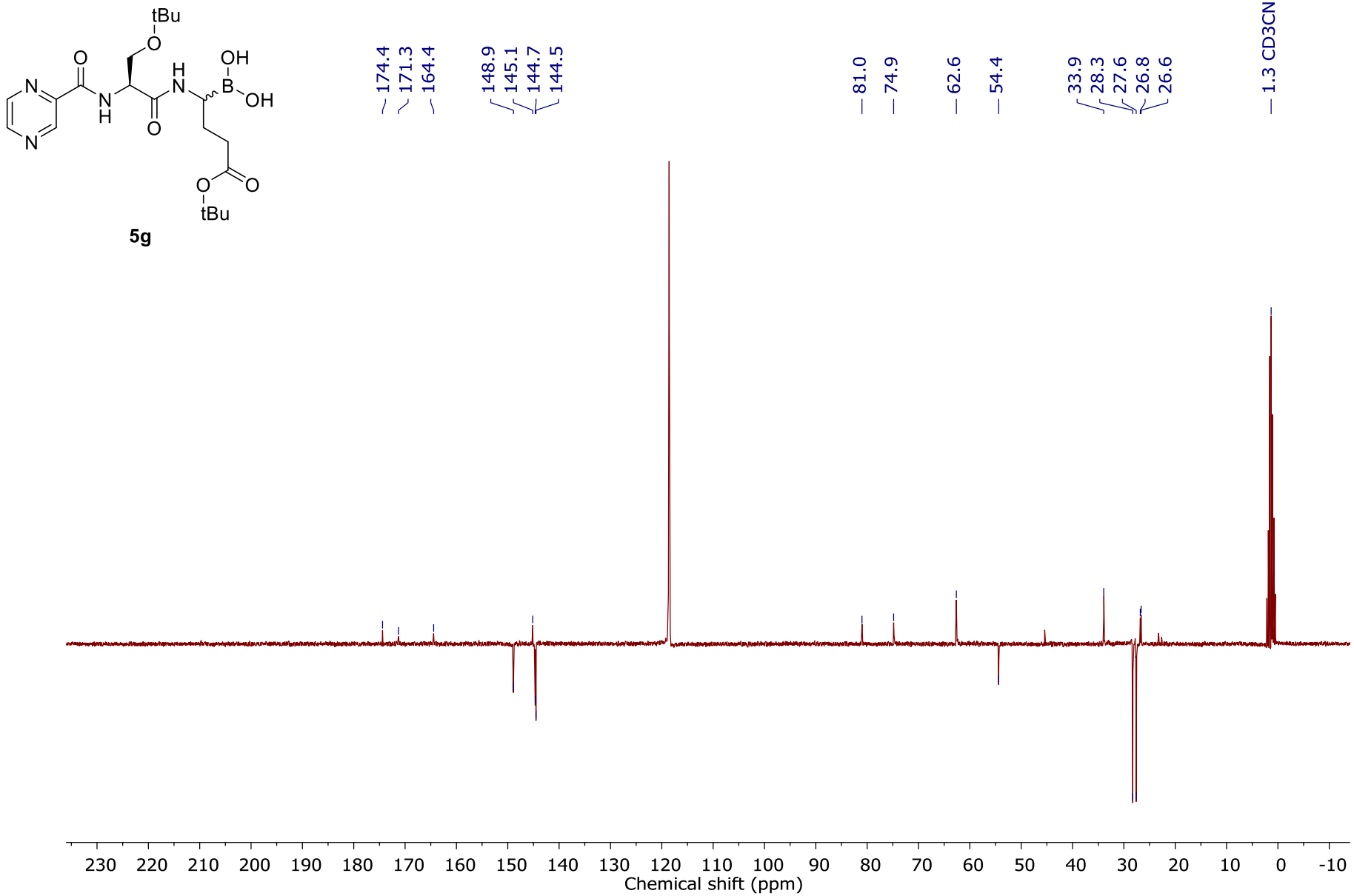

COOH
O
OH
H
N
B
OH
N
H
O
5e
174.2
173.9
172.6
169.4
134.3
133.1
129.6
128.3
128.3
51.2
50.9
36.7
36.7
36.6
36.2
27.9
27.3
17.2
17.1
12.2
11.8
1,3-CD3CN
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

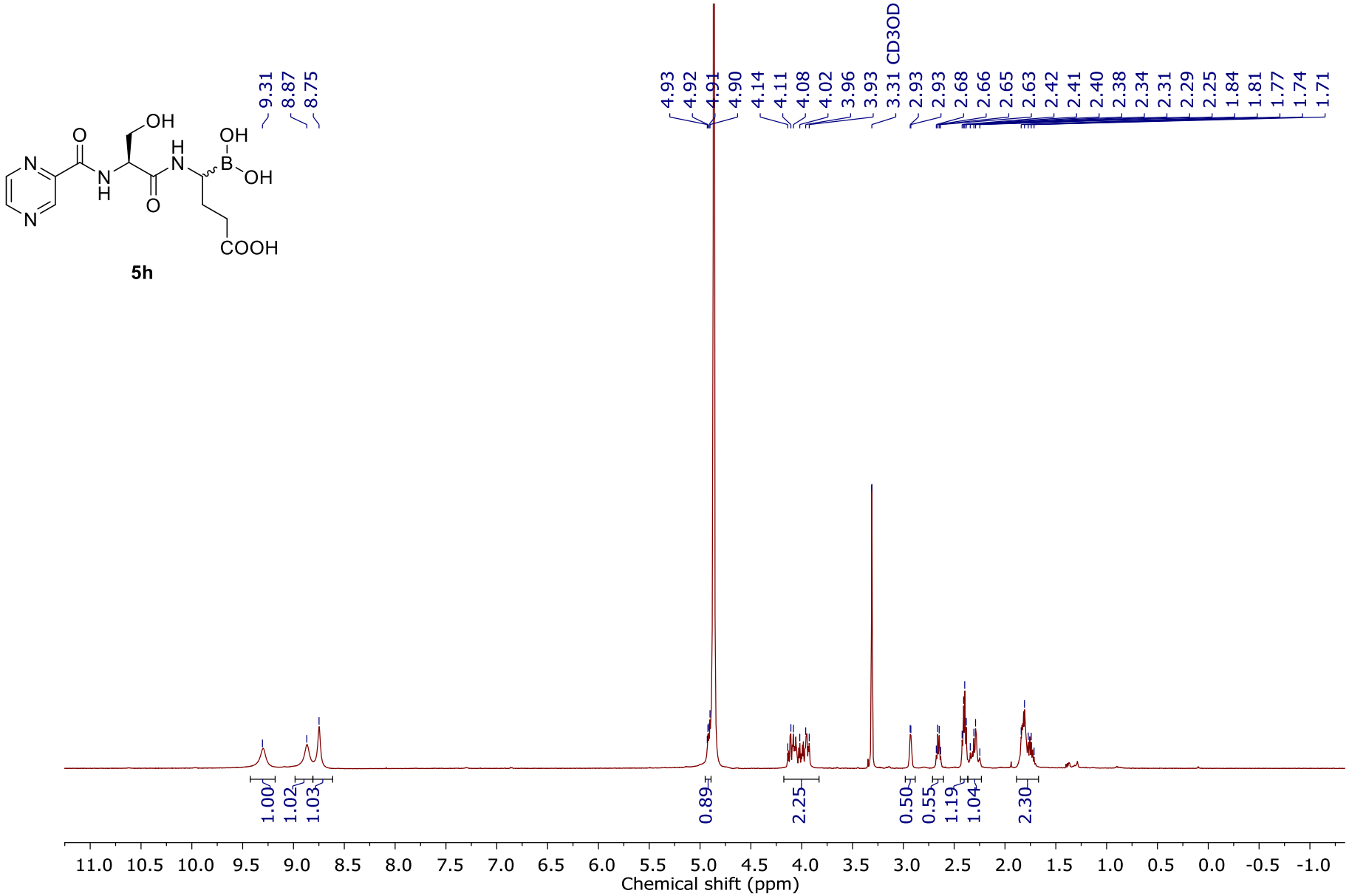

tBu
O
Cl
O
OH
H
N
B
OH
N
O
Cl
Trt
N
H
O
5f
7.53
7.53
7.52
7.43
7.43
7.28
7.25
7.23
7.20
7.18
4.53
4.51
4.50
4.48
3.78
3.75
3.71
3.65
3.60
3.57
3.09
3.06
3.03
3.01
2.99
2.97
2.40
2.33
2.25
1.94 CD3CN
1.84
1.79
1.71
1.66
1.15
0.82
1.75
16.27
0.82
0.81
1.11
1.09
2.17
2.35
8.99
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-
Chemical shift (ppm)


tBu
O
Cl
O
OH
H
N
B
OH
N
O
Cl
Trt
N
H
O
5f
174.2
174.2
171.3
171.3
166.9
166.9
145.8
137.7
133.5
132.5
132.2
130.2
130.1
129.6
128.6
127.7
74.8
74.7
70.8
62.3
55.4
55.3
35.3
27.9
27.8
27.6
1.3 CD3CN
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
Chemical shift (ppm)

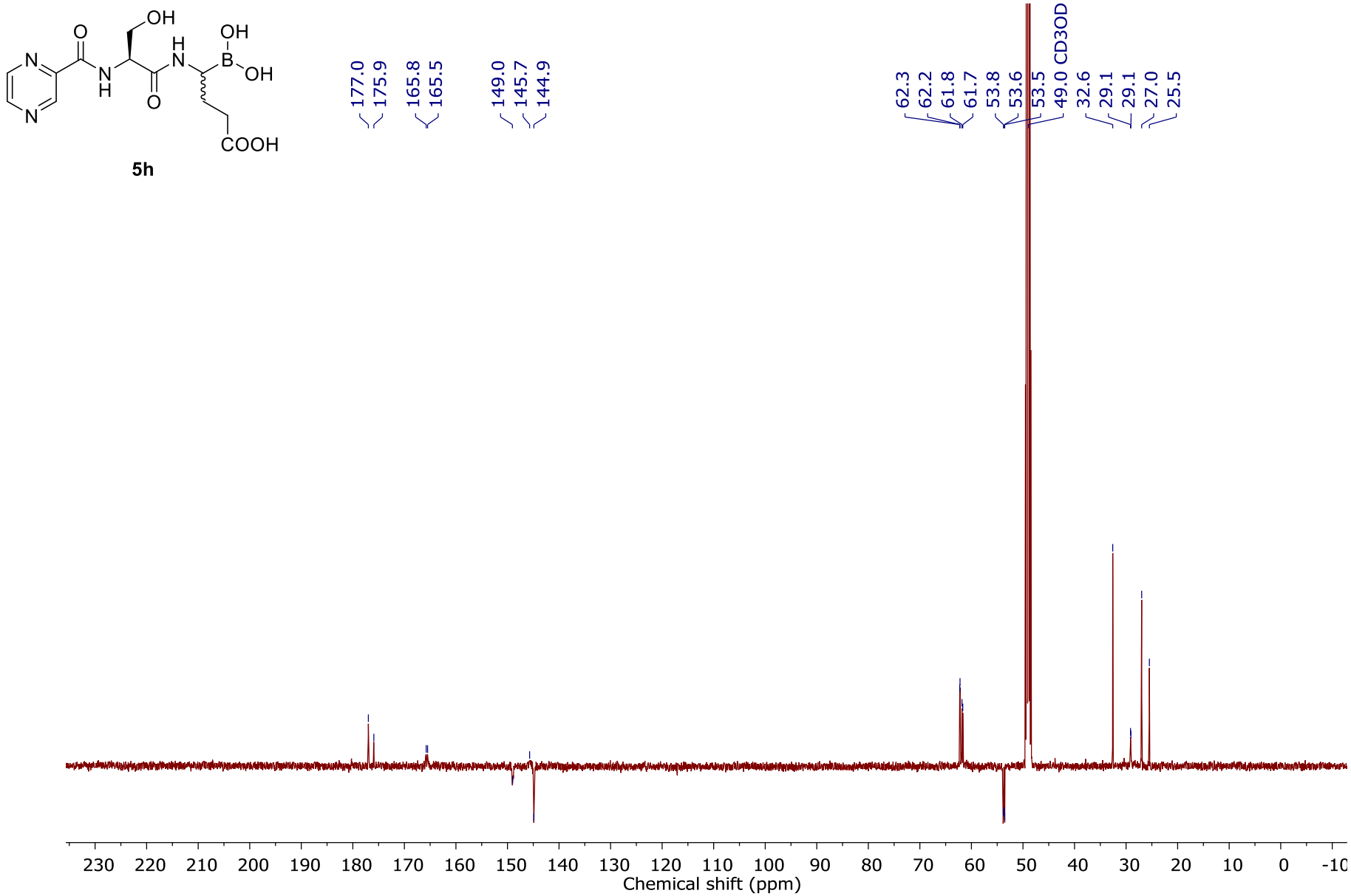

tBu
O
O
N
N
H
O
H
N
OH
B
OH
O
O
O
tBu
9.24
9.23
9.23
8.79
8.79
8.66
8.65
8.65
8.64
4.55
4.53
4.53
4.52
3.85
3.84
3.82
3.82
3.81
3.79
3.65
3.63
3.62
3.60
3.59
3.08
3.04
3.02
2.97
2.27
2.24
2.21
2.16
1.94 CD3CN
1.85
1.80
1.69
1.65
1.37
1.36
1.17
0.83
0.88
0.93
0.82
0.98
1.01
1.10
2.17
2.30
9.25
9.07
12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
Chemical shift (ppm)

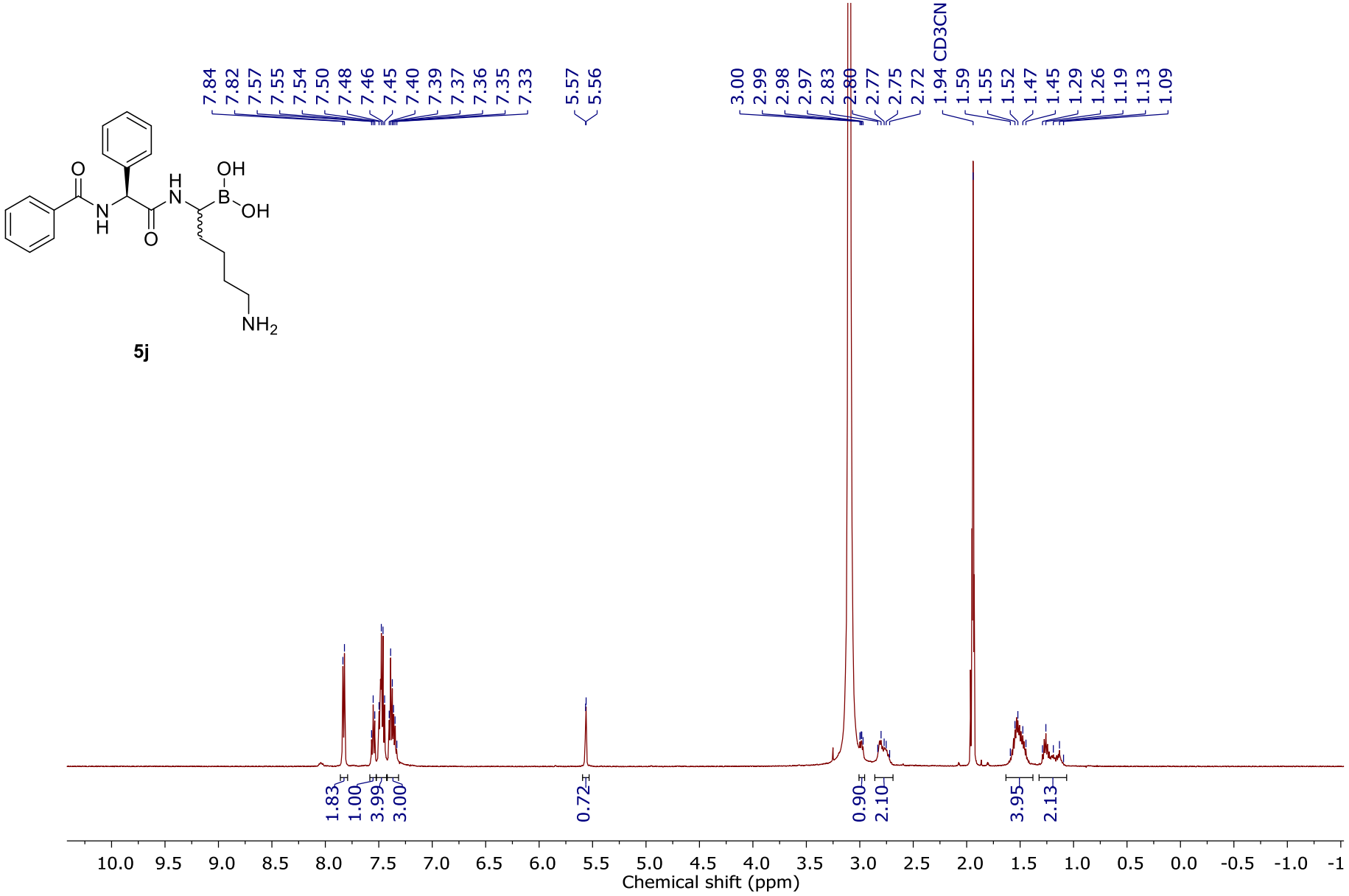
5g


tBu
O
O
N
N
H
O
H
N
OH
B
OH
O
O
O
tBu
5g
174.4
171.3
164.4
148.9
145.1
144.7
144.5
81.0
74.9
62.6
54.4
33.9
28.3
27.6
26.8
26.6
1.3 CD3CN
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
Chemical shift (ppm)

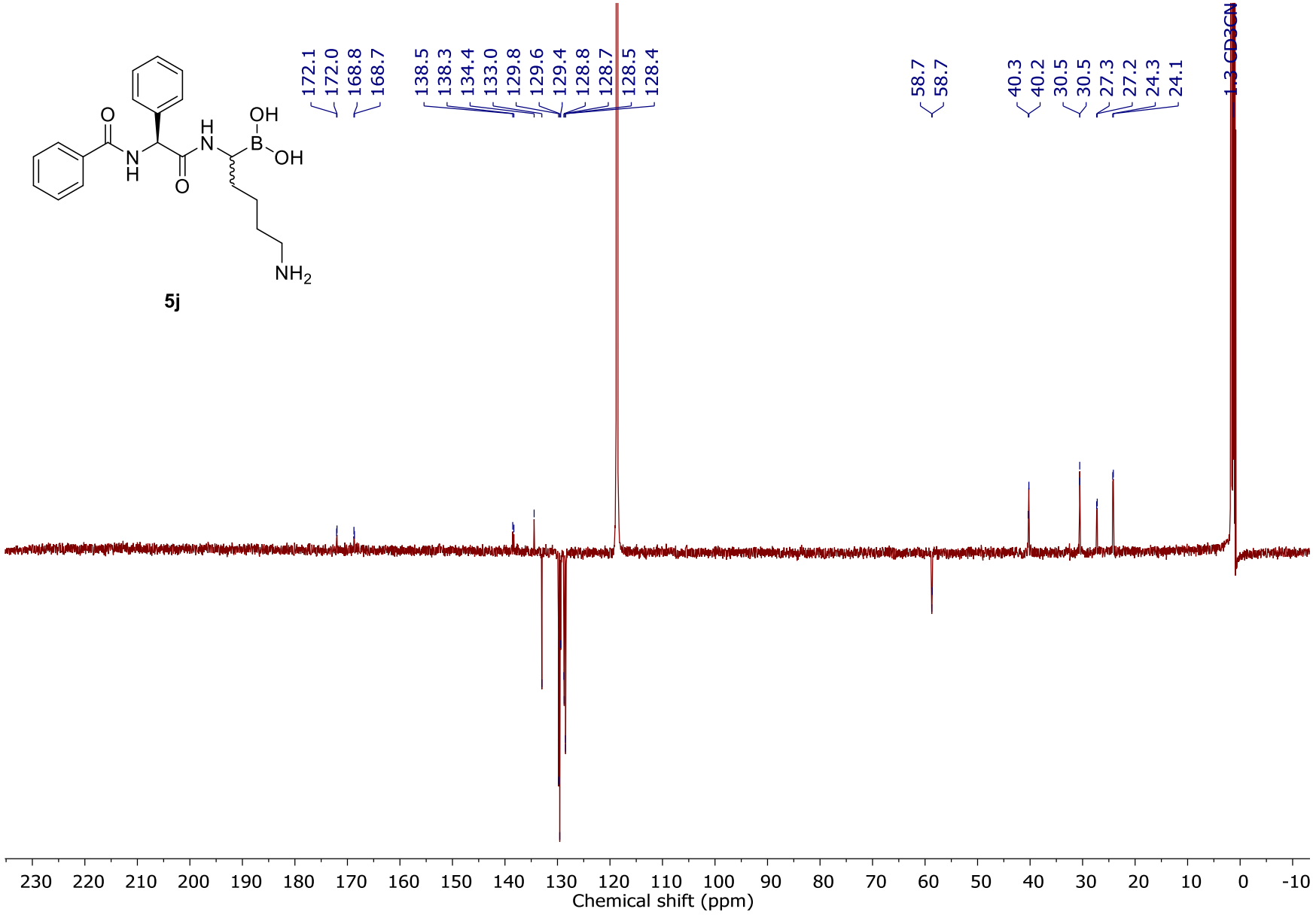

9.31
8.87
8.75
4.93
4.92
4.91
4.90
4.14
4.11
4.08
4.02
3.96
3.93
3.31 CD3OD
2.93
2.93
2.68
2.66
2.65
2.63
2.42
2.41
2.40
2.38
2.34
2.31
2.29
2.25
1.84
1.81
1.77
1.74
1.71
1.00
1.02
1.03
0.89
2.25
0.50
0.55
1.19
1.04
2.30
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0
Chemical shift (ppm)

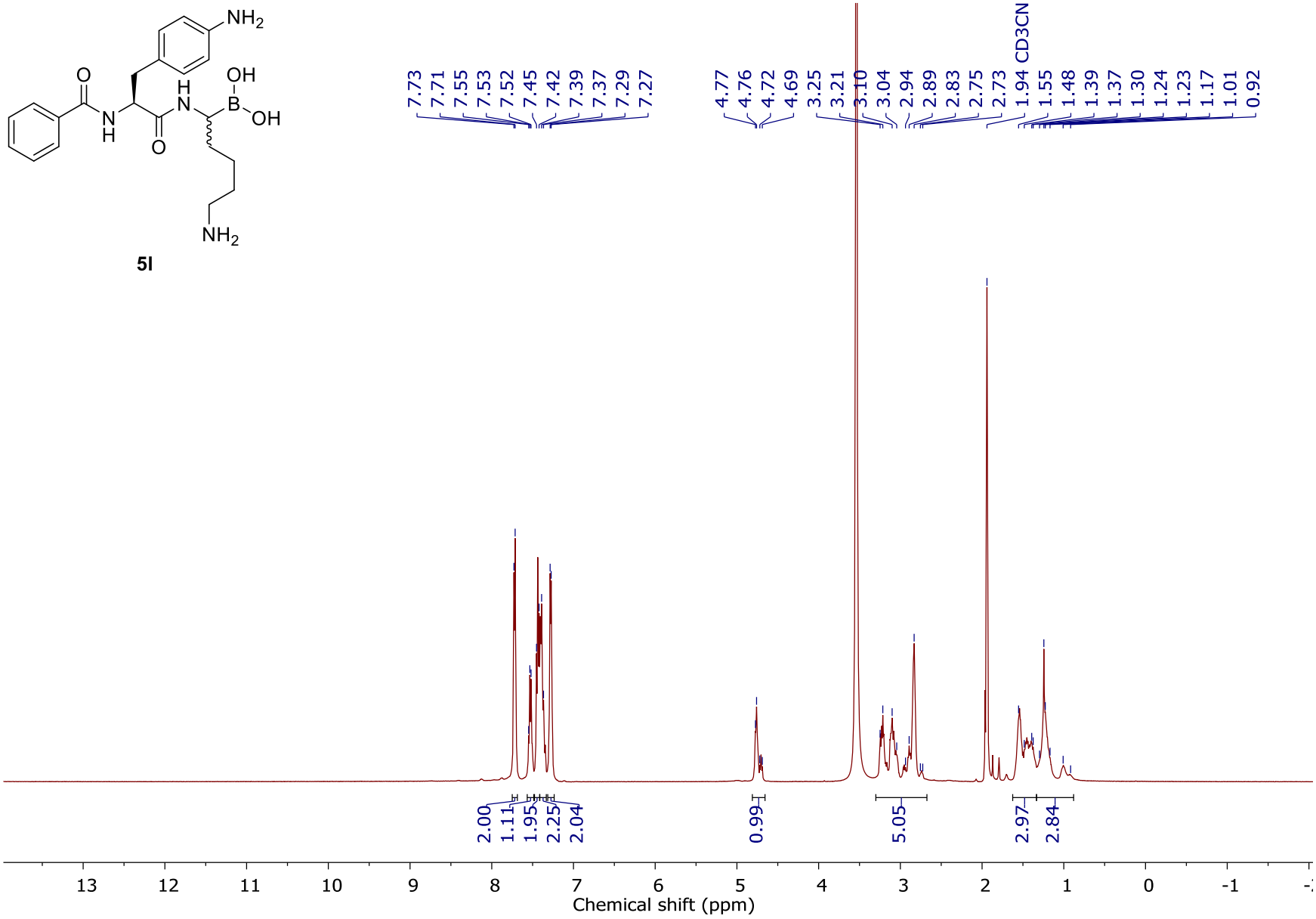
5h

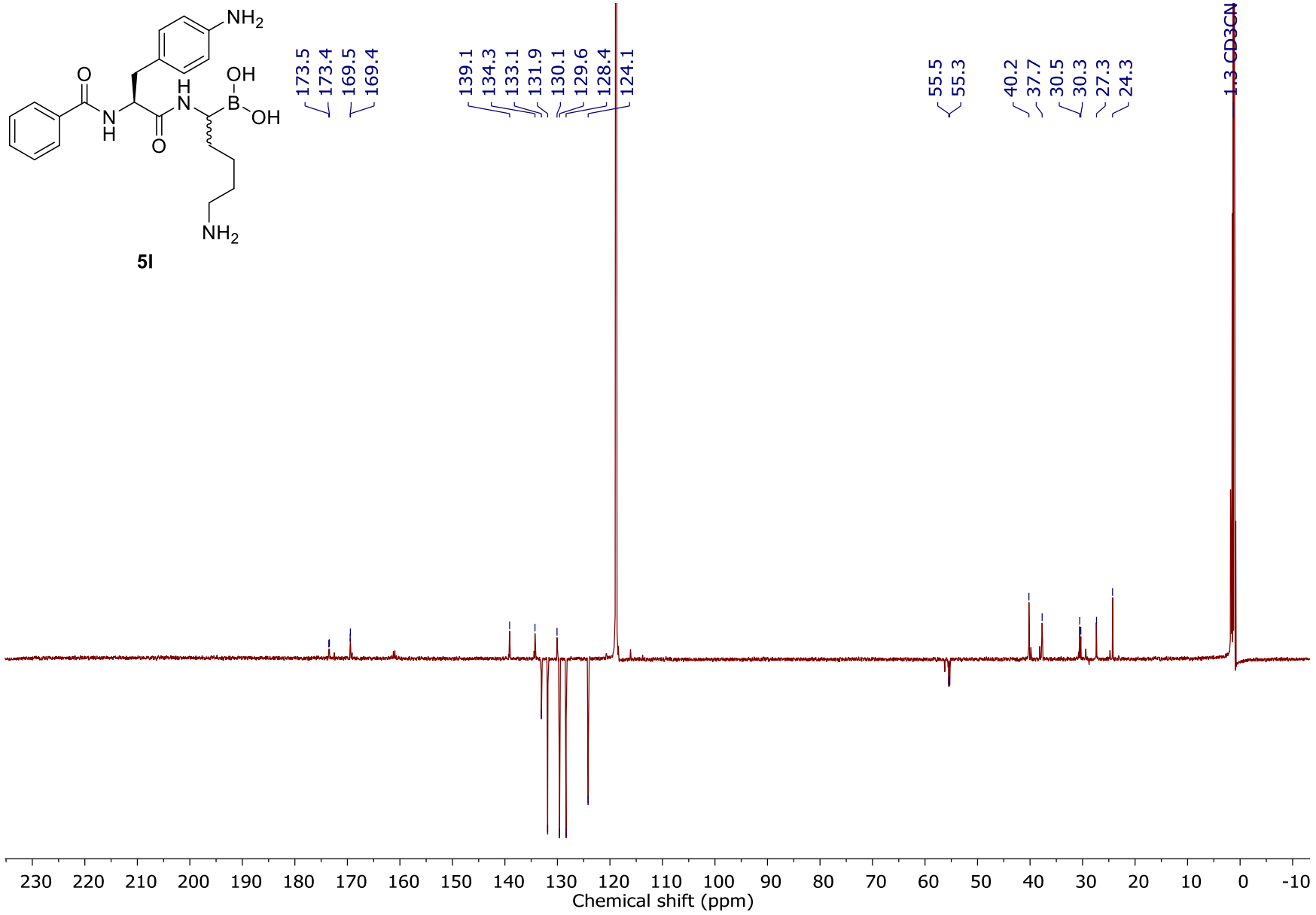

OH
O
OH
N
H
N
B
OH
N
H
O
COOH
5h
177.0
175.9
165.8
165.5
149.0
145.7
144.9
62.3
62.2
61.8
61.7
53.8
53.6
53.5
49.0 CD3OD
32.6
29.1
29.1
27.0
25.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

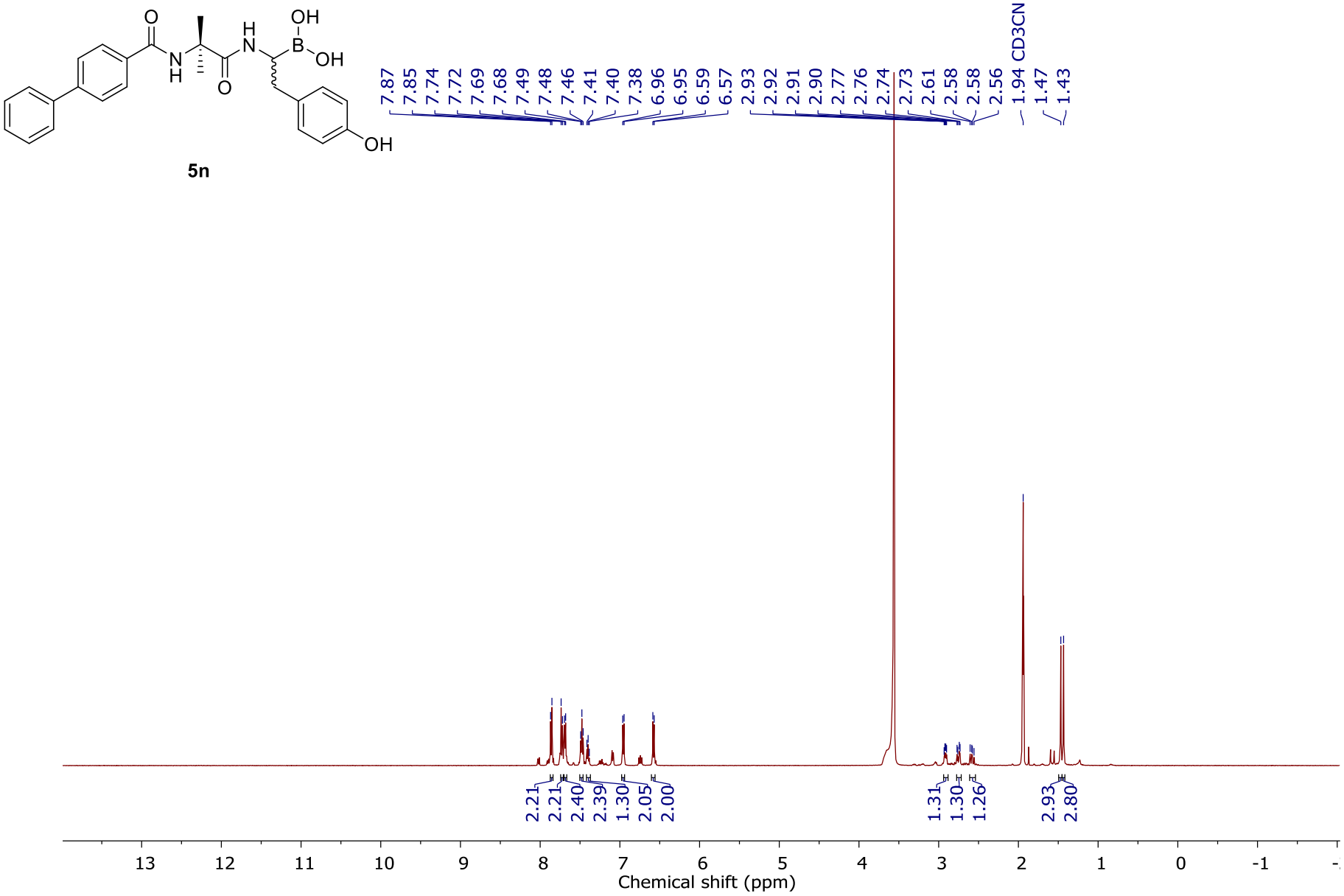

7.84
7.82
7.57
7.55
7.54
7.50
7.48
7.46
7.45
7.40
7.39
7.37
7.36
7.35
7.33
5.57
5.56
3.00
2.99
2.98
2.97
2.83
2.80
2.77
2.75
2.72
1.94 CD3CN
1.59
1.55
1.52
1.47
1.45
1.29
1.26
1.19
1.13
1.09
O
N
H
O
H
N
OH
B
OH
NH2
1.83
1.00
3.99
3.00
0.72
0.90
2.10
3.95
2.13
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.0 -1
Chemical shift (ppm)

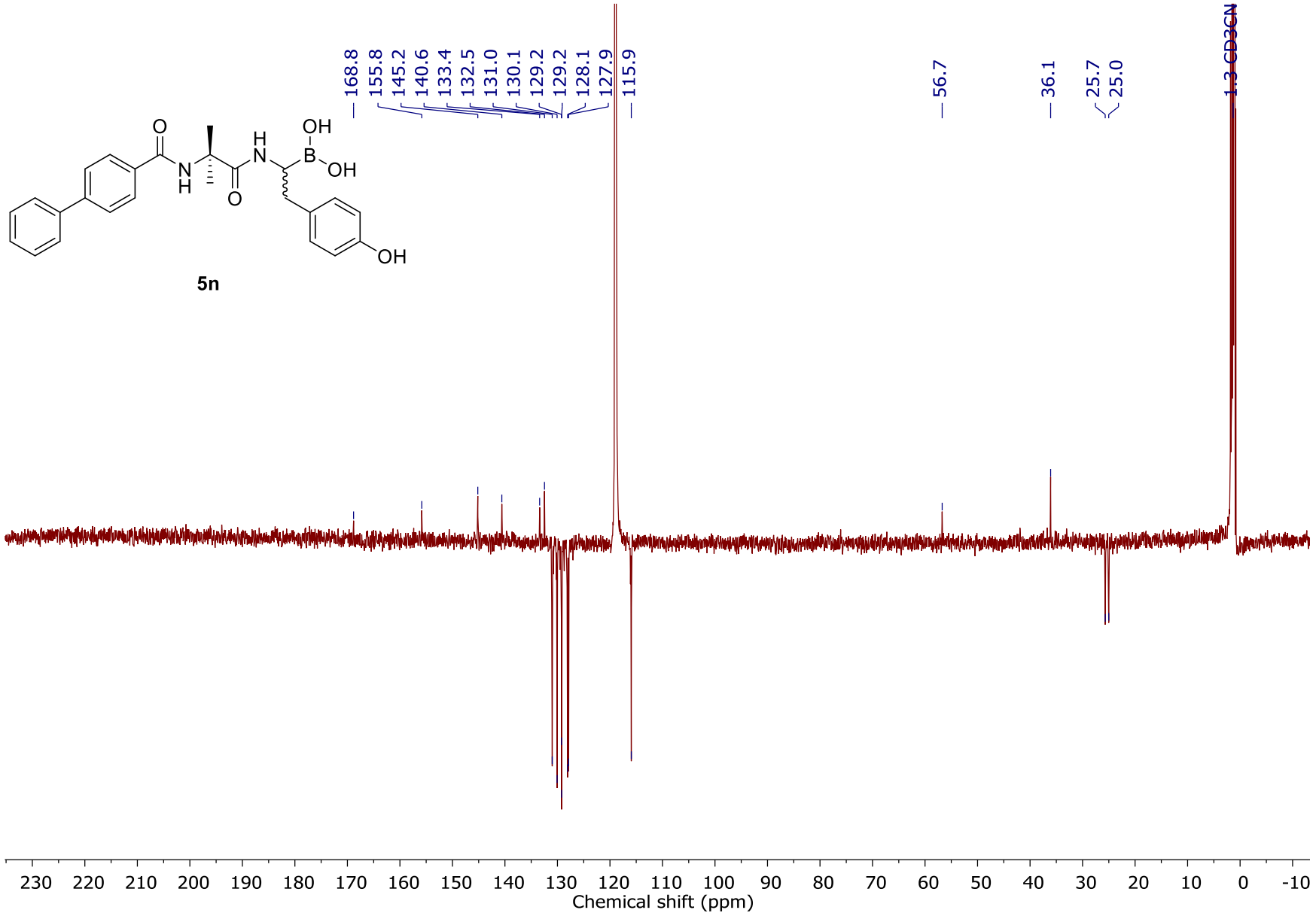
5j


172.1
172.0
168.8
168.7
138.5
138.3
134.4
133.0
129.8
129.6
129.4
128.8
128.7
128.5
128.4
58.7
58.7
40.3
40.2
30.5
30.5
27.3
27.2
24.3
24.1
1.3 CD3CN
O
N
H
O
H
N
OH
B
OH
NH2
5j
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
Chemical shift (ppm)


NH2
OH
B
OH
O
N
H
H
N
O
NH2
5l
7.73
7.71
7.55
7.53
7.52
7.45
7.42
7.39
7.37
7.29
7.27
4.77
4.76
4.72
4.69
3.25
3.21
3.10
3.04
2.94
2.89
2.83
2.75
2.73
1.94 CD3CN
1.55
1.48
1.39
1.37
1.30
1.24
1.23
1.17
1.01
0.92
2.00
1.11
1.95
2.25
2.04
0.99
5.05
2.97
2.84
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


NH2
O
OH
H
N
B
OH
N
H
O
NH2
5l
173.5
173.4
169.5
169.4
139.1
134.3
133.1
131.9
130.1
129.6
128.4
124.1
55.5
55.3
40.2
37.7
30.5
30.3
27.3
24.3
1.3 CD3CN
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
Chemical shift (ppm)


5n
7.87
7.85
7.74
7.72
7.69
7.68
7.49
7.48
7.46
7.41
7.40
7.38
6.96
6.95
6.59
6.57
2.93
2.92
2.91
2.90
2.77
2.76
2.74
2.73
2.61
2.58
2.58
2.56
1.94 CD3CN
1.47
1.43
2.21
2.21
2.40
2.39
1.30
2.05
2.00
1.31
1.30
1.26
2.93
2.80
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
Chemical shift (ppm)


168.8
155.8
145.2
140.6
133.4
132.5
131.0
130.1
129.2
129.2
128.1
127.9
115.9
56.7
36.1
25.7
25.0
1.3 CD3CN
O
N
H
O
H
N
OH
B
OH
OH
5n
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
Chemical shift (ppm)

References

1. J. Cornella, J. T. Edwards, T. Qin, S. Kawamura, J. Wang, C.-M. Pan, R. Gianatassio, M. Schmidt, M. D. Eastgate and P. S. Baran, *Journal of the American Chemical Society*, 2016, **138**, 2174-2177.
2. J. Ma, J. Lin, L. Zhao, K. Harms, M. Marsch, X. Xie and E. Meggers, *Angewandte Chemie International Edition*, 2018, **57**, 11193-11197.
3. J. Wang, H. Lundberg, S. Asai, P. Martín-Acosta, J. S. Chen, S. Brown, W. Farrell, R. G. Dushin, C. J. O'Donnell, A. S. Ratnayake, P. Richardson, Z. Liu, T. Qin, D. G. Blackmond and P. S. Baran, *Proceedings of the National Academy of Sciences*, 2018, **115**, E6404-E6410.
4. C. Li, J. Wang, L. M. Barton, S. Yu, M. Tian, D. S. Peters, M. Kumar, A. W. Yu, K. A. Johnson, A. K. Chatterjee, M. Yan and P. S. Baran, *Science (New York)*, 2017, **356**, eaam7355.
5. A. Ozanne, L. Pouységu, D. Depernet, B. François and S. Quideau, *Organic Letters*, 2003, **5**, 2903-2906.
6. S. P. A. Hinkes and C. D. P. Klein, *Organic Letters*, 2019, **21**, 3048-3052.
7. M. A. M. Behnam, T. R. Sundermann and C. D. Klein, *Organic Letters*, 2016, **18**, 2016-2019.
8. C. Liang, M. A. M. Behnam, T. R. Sundermann and C. D. Klein, *Tetrahedron Letters*, 2017, **58**, 2325-2329.