Supporting Information

Copper-Catalyzed Markovnikov Hydroboration of Aliphatic Terminal Alkenes Using Carbonyl as a Weak Directing Group

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1. General Information

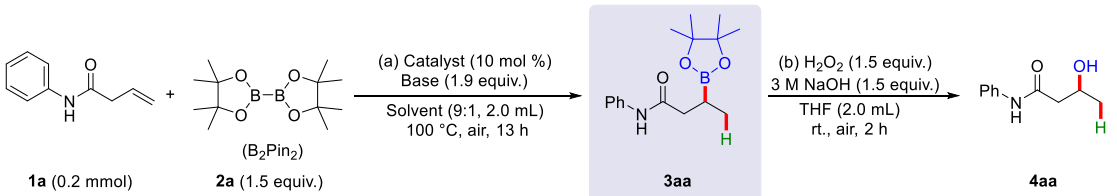
Unless otherwise noted, all manipulations were carried out under an air atmosphere, and all reagents were purchased from commercial suppliers without further purification. Dry MeCN was distilled over sodium hydride. Dry THF was distilled over sodium-benzophenone. All glassware and stirring bars were dried in an oven at 110 °C overnight unless otherwise stated.

Reactions were monitored by Thin Layer Chromatography (TLC) on plates (GF254) visualized by UV or stained with diazotization reagent and bromocresol green. The products were purified by column chromatography over silica gel (200-300 size).

NMR spectra were recorded on Bruker DPX-400 spectrometer (^{1}H: 400 MHz; ^{13}C: 100 MHz; ^{19}F: 376 MHz) and TMS was used as internal standard. ^{1}H, ^{13}C and ^{19}F multiplicities are reported as follows: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, dt = doublet of triplet s, td = triplet of doublets, m = multiplet, br = broad. Melting points were measured using a WC-1 microscopic apparatus and are uncorrected. High resolution mass spectra were ensured on an Agilent Technologies 1290-6540 UHPLC/Accurate-Mass Quadrupole Time-of-Flight LC/MS. X-ray analysis was performed with a single-crystal X-ray diffractometer (Gemini E) from Agilent. The catalytic reactions were heated by heating mantle (MS-H-PROA) from Dlab Sciebtific Co,. Ltd. The scale-up reactions were heated in oil bath.

2. Optimization of Reaction Conditions

Table **S1**. Optimization of Catalysts, Bases and Solvents[a]

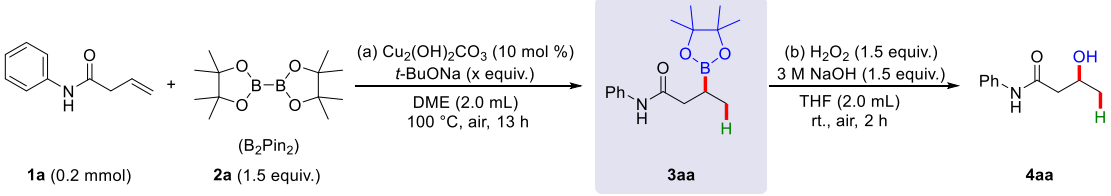


Entry	Catalyst	Base	Solvent	Yield (%)[b]
1	CuCl	*t*-BuONa	acetone:hexane (9:1)	57
2	CuOAc	*t*-BuONa	acetone:hexane (9:1)	72
3	Cu_2O	*t*-BuONa	acetone:hexane (9:1)	70
4	$CuF_2·2H_2O$	*t*-BuONa	acetone:hexane (9:1)	55
5	$CuCl_2$	*t*-BuONa	acetone:hexane (9:1)	63
6	$CuBr_2$	*t*-BuONa	acetone:hexane (9:1)	51
7	$Cu(OAc)_2·H_2O$	*t*-BuONa	acetone:hexane (9:1)	75
8	$Cu(OAc)_2$	*t*-BuONa	acetone:hexane (9:1)	70
9	**$Cu_2(OH)_2CO_3$**	***t*-BuONa**	**acetone:hexane (9:1)**	**84**
10	$Cu(OH)_2$	*t*-BuONa	acetone:hexane (9:1)	68
11	$CuSO_4$	*t*-BuONa	acetone:hexane (9:1)	67
Conclusion for the catalyst screening (entries 1-11): $Cu_2(OH)_2CO_3$ is the best catalyst.				
12	$Cu_2(OH)_2CO_3$	*t*-BuOLi	acetone:hexane (9:1)	<5
13	$Cu_2(OH)_2CO_3$	*t*-BuOK	acetone:hexane (9:1)	59

14	$Cu_2(OH)_2CO_3$	Na_2CO_3	acetone:hexane (9:1)	<5
15	$Cu_2(OH)_2CO_3$	K_2CO_3	acetone:hexane (9:1)	30
16	$Cu_2(OH)_2CO_3$	Cs_2CO_3	acetone:hexane (9:1)	<5
17	$Cu_2(OH)_2CO_3$	NaOAc	acetone:hexane (9:1)	<5
18	$Cu_2(OH)_2CO_3$	CsOAc	acetone:hexane (9:1)	<5
19	$Cu_2(OH)_2CO_3$	NaOPiv	acetone:hexane (9:1)	<5
20	$Cu_2(OH)_2CO_3$	Na_3PO_4	acetone:hexane (9:1)	<5
21	$Cu_2(OH)_2CO_3$	K_3PO_4	acetone:hexane (9:1)	<5
22	$Cu_2(OH)_2CO_3$	Na_2HPO_4	acetone:hexane (9:1)	<5
23	$Cu_2(OH)_2CO_3$	NaOMe	acetone:hexane (9:1)	22
24	$Cu_2(OH)_2CO_3$	NaOEt	acetone:hexane (9:1)	<5
Conclusion for the base screening (entries 9, 12-24): *t*-BuONa remains best.				
25	$Cu_2(OH)_2CO_3$	*t*-BuONa	acetone	58
26	$Cu_2(OH)_2CO_3$	*t*-BuONa	DCE	53
27	$Cu_2(OH)_2CO_3$	*t*-BuONa	CH_3CN	55
28	$Cu_2(OH)_2CO_3$	*t*-BuONa	EA	65
29	$Cu_2(OH)_2CO_3$	*t*-BuONa	$HCCl_3$	<10
30	$Cu_2(OH)_2CO_3$	*t*-BuONa	DMF	70
31	$Cu_2(OH)_2CO_3$	*t*-BuONa	Chlorobenzene	66
32	$Cu_2(OH)_2CO_3$	*t*-BuONa	*i*-PrOH	79
33	$Cu_2(OH)_2CO_3$	*t*-BuONa	*t*-AmylOH	67
34	$Cu_2(OH)_2CO_3$	*t*-BuONa	Hexane	52
35	$Cu_2(OH)_2CO_3$	*t*-BuONa	Dioxane	83
36	$Cu_2(OH)_2CO_3$	*t*-BuONa	THF	89
37	$Cu_2(OH)_2CO_3$	*t*-BuONa	2-MeTHF	83
38	**$Cu_2(OH)_2CO_3$**	***t*-BuONa**	**DME**	**95**
39	$Cu_2(OH)_2CO_3$	*t*-BuONa	MTBE	77
40	$Cu_2(OH)_2CO_3$	*t*-BuONa	CPME	57
Conclusion for the solvent screening (entries 25-40): DME is the best solvent.				

[a]Reaction conditions: (a) **1a** (0.2 mmol), **2a** (1.5 equiv.), Catalyst (10 mol %), Base (1.9 equiv.) in Solvent (2.0 mL) at 100 °C under air for 13 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

Table **S2**. Optimization of the Base Loading [a]

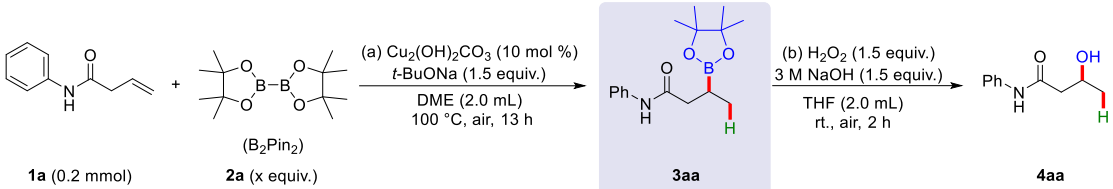


Entry	Base Loading	Yield (%)[b]
1	1.0 equiv.	43

2	1.2 equiv.	67
3	**1.5 equiv.**	**94**
4	2.0 equiv.	96

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (1.5 equiv.), $Cu_2(OH)_2CO_3$ (10 mol %), *t*-BuONa (x equiv.) in DME (2.0 mL) at 100 °C under air for 13 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

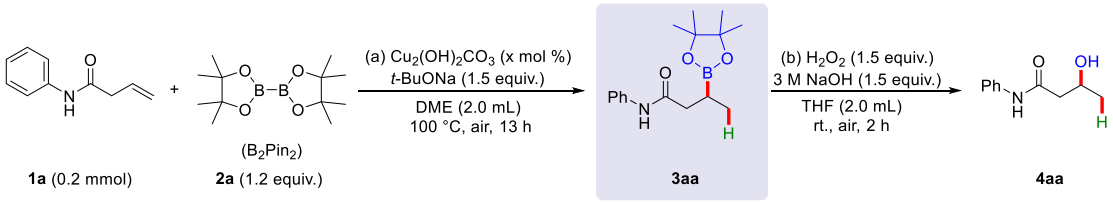
Table **S3**. Optimization of the B_2Pin_2 Loading[a]



Entry	B_2Pin_2 Loading	Yield (%)[b]
1	1.0 equiv.	80
2	**1.2 equiv.**	**95**
3	1.5 equiv.	94
4	2.0 equiv.	90

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (x equiv.), $Cu_2(OH)_2CO_3$ (10 mol %), *t*-BuONa (1.5 equiv.) in DME (2.0 mL) at 100 °C under air for 13 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

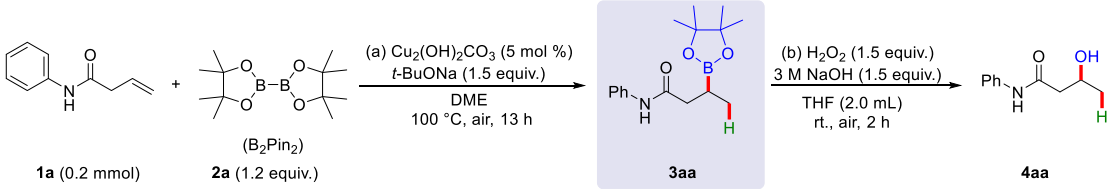
Table **S4**. Optimization of the Catalyst Loading[a]



Entry	Catalyst Loading	Yield (%)[b]
1	2.0 mol %	90
2	**5.0 mol %**	**96**
3	10.0 mol %	95
4	15.0 mol %	95

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (1.2 equiv.), $Cu_2(OH)_2CO_3$ (x mol %), *t*-BuONa (1.5 equiv.) in DME (2.0 mL) at 100 °C under air for 13 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

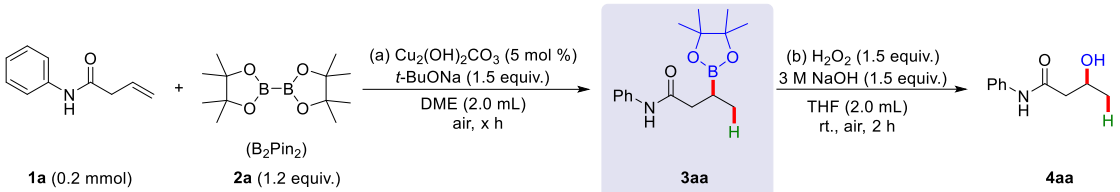
Table **S5**. Optimization of the Solvent Amount[a]



Entry	Solvent Amount (mL)	Yield (%)[b]
1	0.5	84
2	1.0	94
3	1.5	95
4	**2.0**	**96**

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (1.2 equiv.), $Cu_2(OH)_2CO_3$ (5 mol %), *t*-BuONa (1.5 equiv.) in DME at 100 °C under air for 13 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

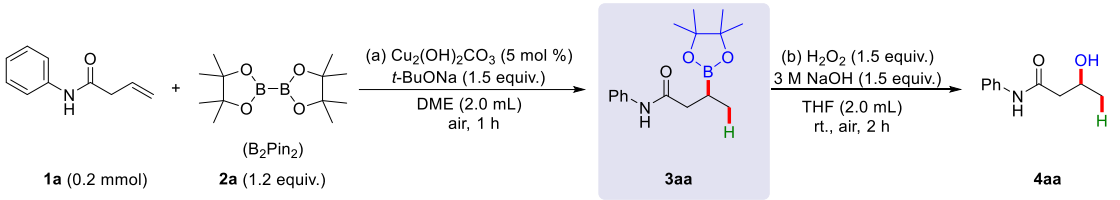
Table **S6**. Optimization of the Time[a]



Entry	Time (h)	Yield (%)[b]
1	0.25	85
2	**1**	**95**
3	2	90
4	8	94
5	10	94

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (1.2 equiv.), $Cu_2(OH)_2CO_3$ (5 mol %), *t*-BuONa (1.5 equiv.) in DME (2.0 mL) at 100 °C under air. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

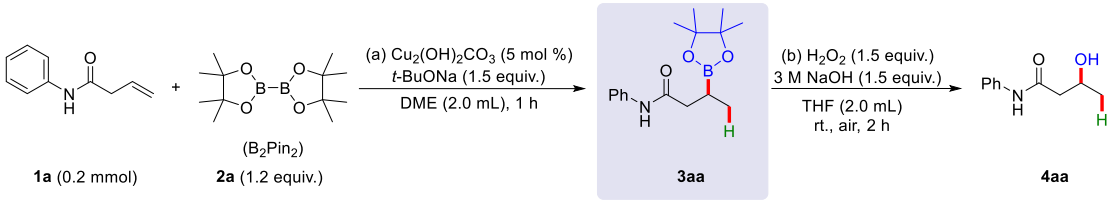
Table **S7**. Optimization of the Temperature[a]



Entry	Temperature (°C)	Yield (%)[b]
1	50	73
2	80	66
3	100	95

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (1.2 equiv.), $Cu_2(OH)_2CO_3$ (5 mol %), *t*-BuONa (1.5 equiv.) in DME (2.0 mL) under air for 1 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

Table **S8**. Optimization of the Atmosphere[a]

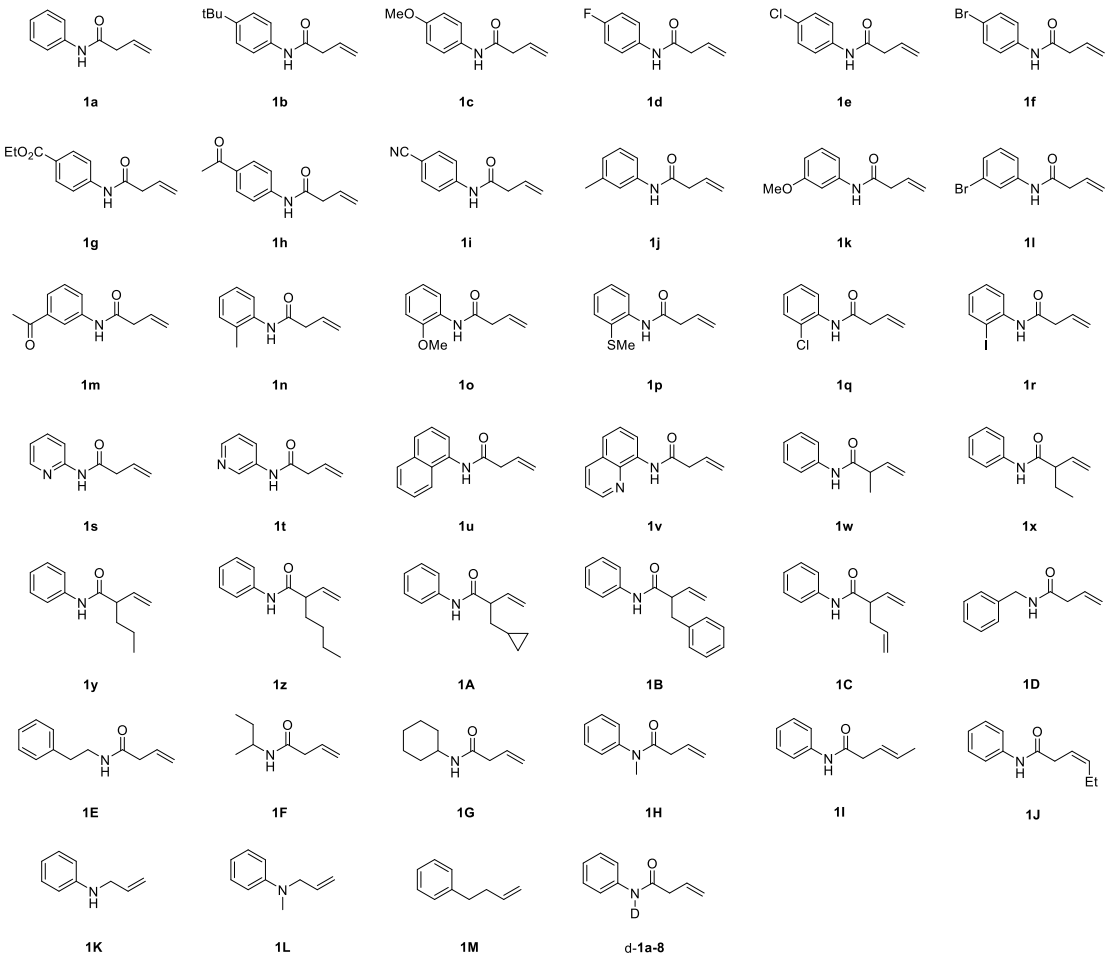


Entry	Atmosphere	Yield (%)[b]
1	Ar	84
2	N_2	77
3	O_2	32
4	air	95

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (1.2 equiv.), $Cu_2(OH)_2CO_3$ (5 mol %), *t*-BuONa (1.5 equiv.) in DME (2.0 mL) at 100 °C for 1 h. (b) H_2O_2 (1.5 equiv.), 3 M NaOH aq. (1.5 equiv.), THF (2.0 mL), rt., air, 2 h. [b]Isolated yield.

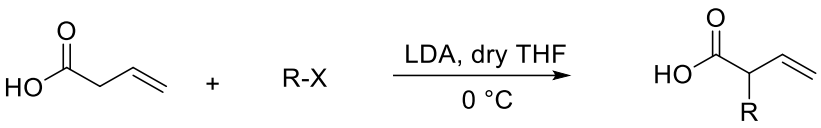
3. Experimental Procedures

3.1 General Procedure for Synthesis of Alkene Substrates 1



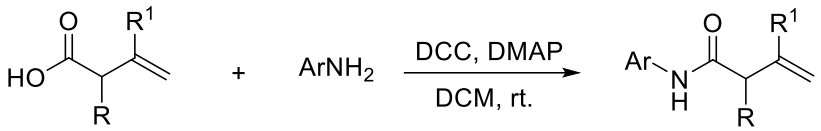
Alkene substrates **1a-1M**were prepared according to the reported procedures.[1]

3.1.1 General Procedure for α-Substituted Vinyl Acetic Acids



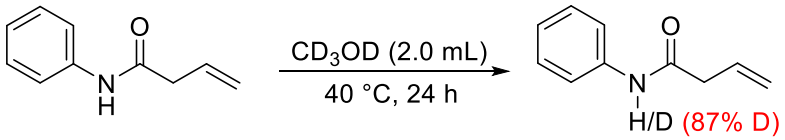
A solution of LDA (6.6 ml, 13.2 mmol, 2.0 M in THF, 2.2 equiv.) in dry THF (8.0 mL) was added to a solution of vinyl acetic acid (6.0 mmol, 1.0 equiv.) in dry THF (3.0 mL) dropwise at 0 °C, and the resulting solution was stirred for 45 min. Then an alkylating agent (10.0 mmol, 1.0 equiv.) was added slowly at 0 °C and then the mixture was stirred for 30 min. After that, the resulting mixture was stirred for 3 h at room temperature, and water was added to the mixture. The mixture was acidified with 1 M hydrochloric acid until pH = 2~3. The milky solution was then extracted with EtOAc (3 × 40.0 mL). The combined organic layers were dried by anhydrous Na_2SO_4, filtered and concentrated under reduced pressure. Analysis of the crude ^1H NMR spectrum revealed the amount of the desired acid. The combined organic layers were carried forward to the next step without further purification.

3.1.2 General Procedure for Substrates 1



A 100 mL two-necked round-bottom flask was equipped with a magnetic stir bar and charged with corresponding vinyl acetic acid (1.1 mL, 13.0 mmol), arylamine (1.44 g, 10.0 mmol), DMAP (0.1 equiv., 1.3 mmol) in 30.0 mL anhydrous CH_2Cl_2 at 0 °C. After DCC (1.1 equiv., 13.0 mmol) in CH_2Cl_2 (20.0 mL) was added dropwise to the solution, the reaction was then warmed to room temperature and stirred for 16 h. The deep brown solution was diluted with EtOAc (80.0 mL), and washed with sat. $NaHCO_3$ (2 × 70.0 mL) and brine (1 × 70.0 mL). The combined organic solvent was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The resulting residue was purified by column chromatography (hexane/ethyl acetate = 15:1) (V/V) to afford the target product.

The Procedure for Deuterated Substrate d-**1a-8**:



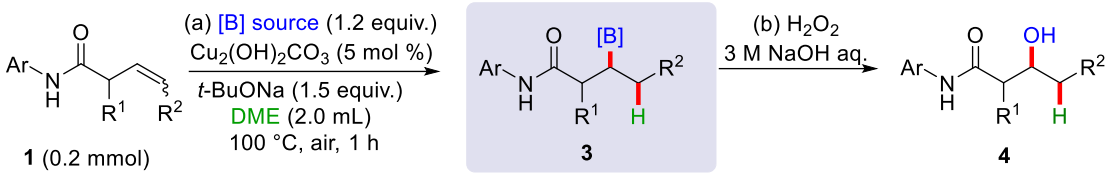
1a d-**1a-8**

A 10 mL round-bottom flask was equipped with a magnetic stir bar and charged with alkene **1a** (2.0 mmol) in CD_3OD (2.0 mL) heated at 40 °C for 24 h. Upon completion, the reaction mixture was cooled to room temperature and concentrated under vacuum to afford corresponding product d-**1a-8**.

Deuterated-*N*-phenylbut-3-enamide (d-**1a-8**): white solid (hexane/EtOAc = 8/1, R_f = 0.3, yield: >99%), mp 54-56 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 7.51-7.49 (m, 2H), 7.41 (s, 0.13H), 7.33-

7.29 (m, 2H), 7.12-7.08 (m, 1H), 6.08-5.98 (m, 1H), 5.34-5.29 (m, 2H), 3.18-3.16 (d, J = 7.19 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.7, 137.7, 131.0, 129.9, 124.4, 120.4, 119.8, 42.6; ^{2}H NMR (61 MHz, $CDCl_3$) δ 7.94 (s).

3.2 General Procedure for Products 3 and 4

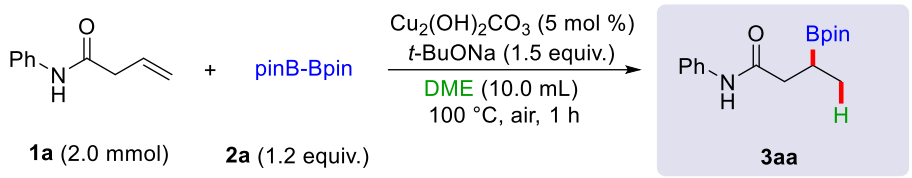


A Schlenk tube was equipped with a magnetic stir bar and charged with an alkene **1** (0.2 mmol, 1.0 equiv.), diboron source (0.24 mmol, 1.2 equiv.), $Cu_2(OH)_2CO_3$ (0.01 mmol, 0.05 equiv.), *t*-BuONa (0.3 mmol, 1.5 equiv.) in DME (2.0 mL) heated at 100 ℃ for 1 h. Upon completion, the reaction mixture was cooled to room temperature, and DCM (20.0 mL) was added. The resulting mixture was filtered through a pad of Celite, concentrated in vacuum. The residue was purified by column chromatography on silica gel (100-200 mesh) to afford a corresponding product **3**.

General Procedure for Boronate Oxidation:

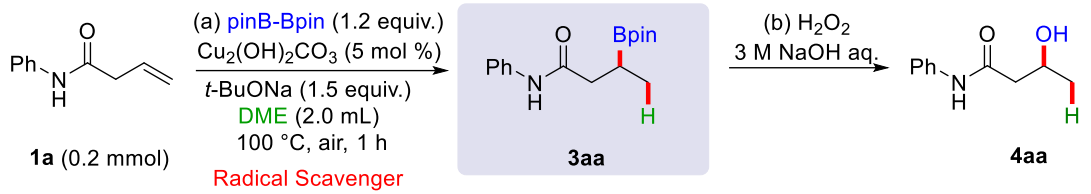
The crude boronate ester, THF (2.0 mL), and NaOH aqueous solution (3 M, 1.5 equiv.) were added to a 5 mL reaction tube. H_2O_2 (30% w/w in water, 1.5 equiv.) was added to the vessel dropwise at 0 ℃. The reaction mixture was then stirred at room temperature for 2-3 h until the boronate ester was completely consumed. Water (5.0 mL) was added, and the solution was extracted with EtOAc (2 × 10.0 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under vacuum. The residue was purified by column chromatography on silica gel (100-200 mesh) to afford a corresponding product **4**.

3.3 Scale-up Experiment



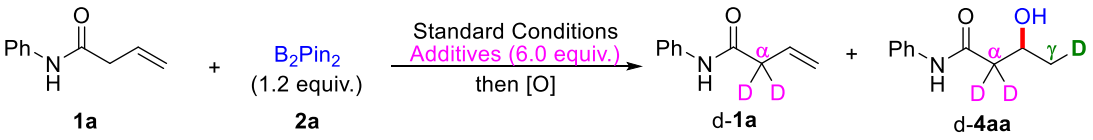
A Schlenk tube was equipped with a magnetic stir bar and charged with an alkene **1a** (2.0 mmol, 1.0 equiv.), pinB-Bpin (2.4 mmol, 1.2 equiv.), $Cu_2(OH)_2CO_3$ (0.1 mmol, 0.05 equiv.), *t*-BuONa (3.0 mmol, 1.5 equiv.) in DME (10.0 mL) heated at 100 ℃ for 1 h. Upon completion, the reaction mixture was cooled to room temperature, diluted with EtOAc (2 × 20.0 mL). The combined organic layers were washed with brine (1 × 20.0 mL), dried over Na_2SO_4, and concentrated under vacuum. The residue was purified by column chromatography on silica gel (100-200 mesh) to afford a corresponding product **3aa** (80%, 480 mg).

3.4 The Radical Trapping Experiments



A Schlenk tube was equipped with a magnetic stir bar and charged with an alkene **1a** (0.2 mmol, 1.0 equiv.), pinB-Bpin (0.24 mmol, 1.2 equiv.), $Cu_2(OH)_2CO_3$ (0.01 mmol, 0.05 equiv.), *t*-BuONa (0.2 mmol, 1.5 equiv.), BHT, TEMPO or 1,1-diphenylethylene (0.4 mmol, 2.0 equiv.) in DME (2.0 mL) heated at 100 ℃ for 1 h. Upon completion, the reaction mixture was cooled to room temperature, the crude boronate ester, THF (2.0 mL), and NaOH aqueous solution (3 M, 1.5 equiv.) were added to a 5.0 mL reaction tube. H_2O_2 (30% w/w in water, 1.5 equiv.) was added to the vessel dropwise at 0 ℃. The reaction mixture was then stirred at room temperature for 2-3 h until the boronate ester was completely consumed. Water (5.0 mL) was added, and the solution was extracted with EtOAc (2 × 10.0 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under vacuum. The residue was purified by column chromatography on silica gel (100-200 mesh) to afford a corresponding product **4**.

3.5 Deuterium Labeling Experiments



Additives = D_2O

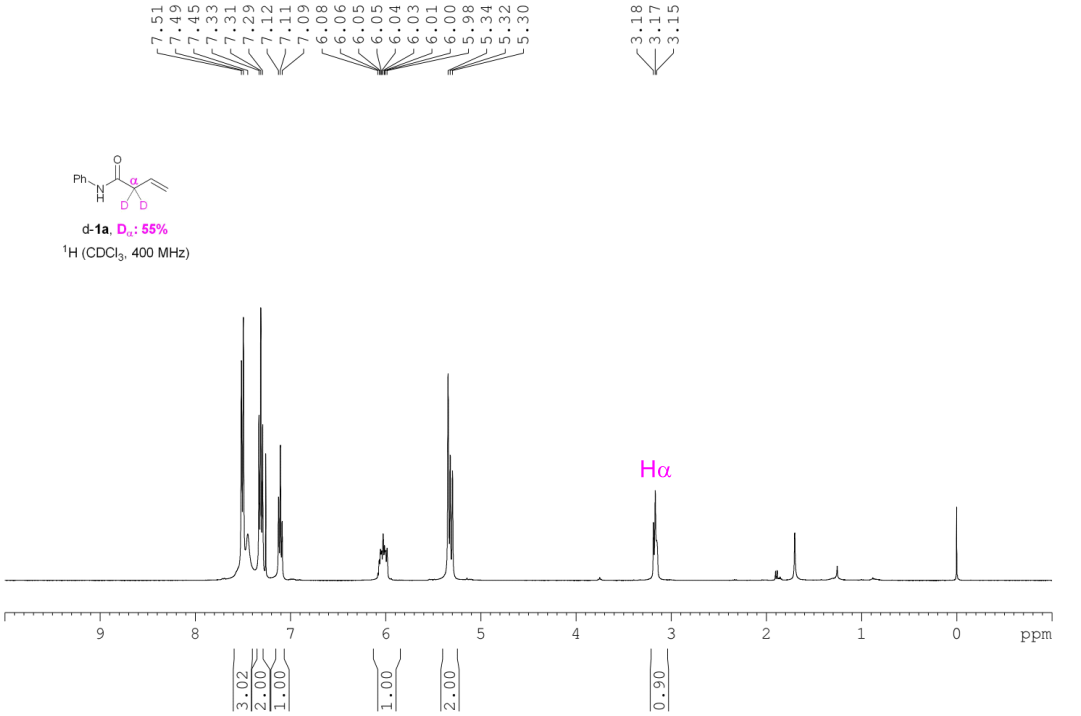
DME	THF	Dioxane	DMF
d-**1a**, 30%, D_α: 55% d-**4aa**, 53%, D_α: 26% D_γ: 0%	d-**1a-1**, 50%, D_α: 21% d-**4aa-1**, 36%, D_α: 20% D_γ: 0%	d-**1a-2**, 57%, D_α: 27% d-**4aa-2**, 35%, D_α: 29% D_γ: 0%	d-**1a-3**, trace d-**4aa-3**, 56%, D_α: 32% D_γ: 0%

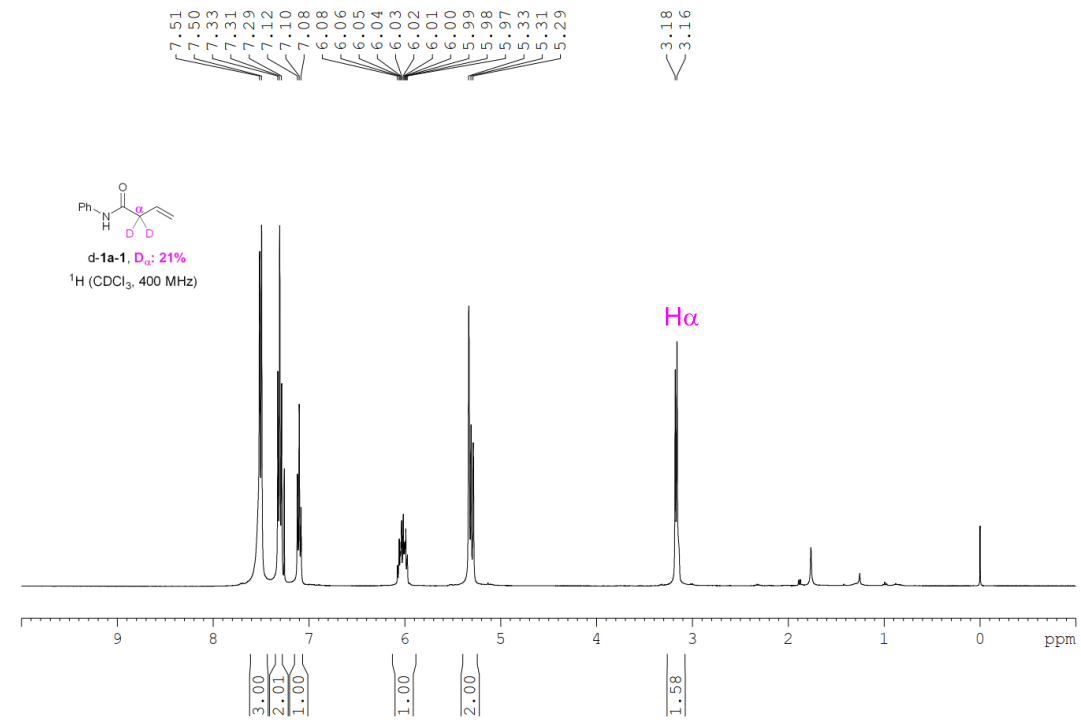
Additives = CD_3OD

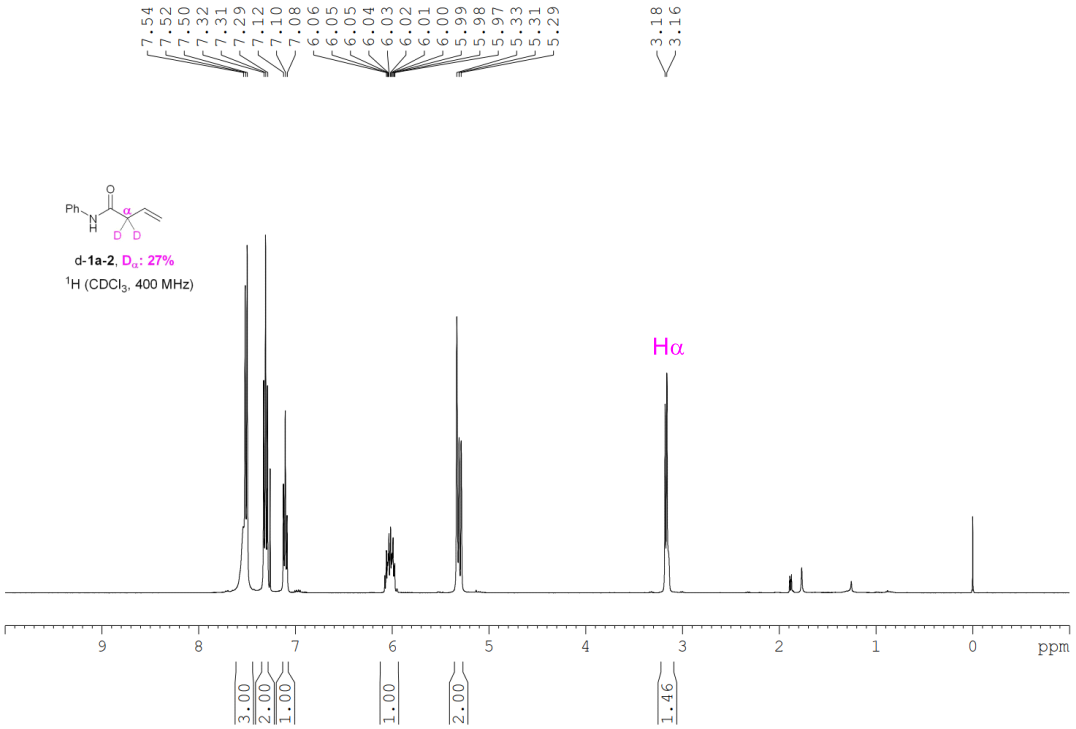
DME	THF	Dioxane	DMF
d-**1a-4**, 17%, D_α: 57% d-**4aa-4**, 77%, D_α: 20% D_γ: 0%	d-**1a-5**, 34%, D_α: 34% d-**4aa-5**, 39%, D_α: 18% D_γ: 0%	d-**1a-6**, - d-**4aa-6**, 49%, D_α: 19% D_γ: 0%	d-**1a-7**, trace d-**4aa-7**, 41%, D_α: 20% D_γ: 0%

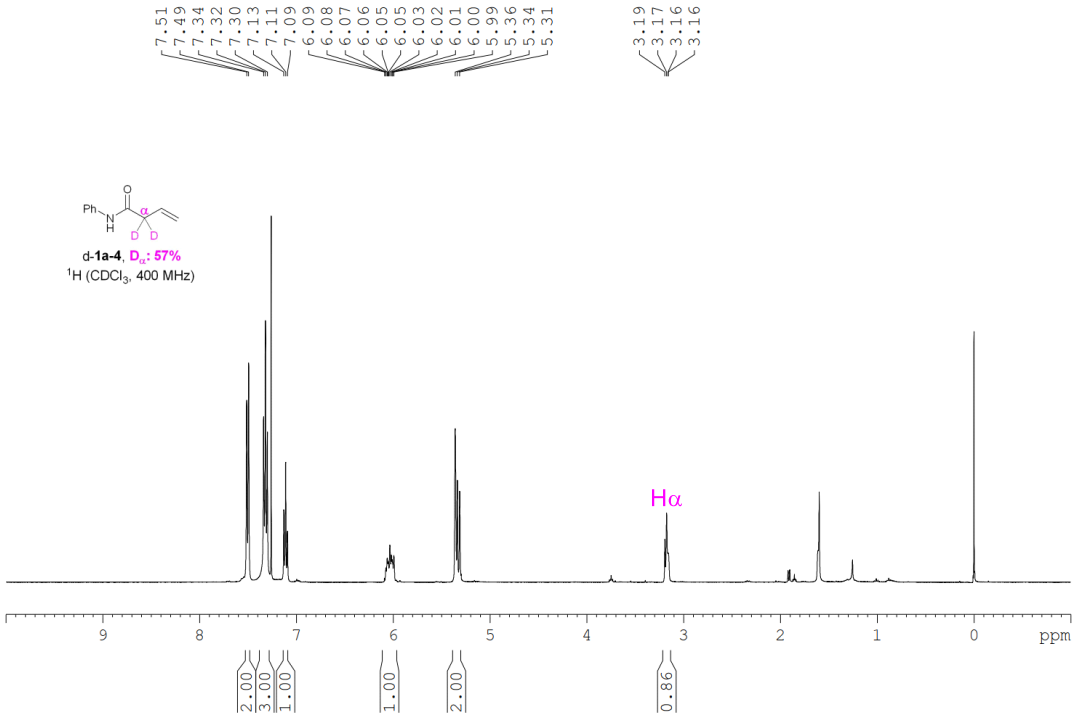
A Schlenk tube was equipped with a magnetic stir bar and charged with an alkene **1a** (0.2 mmol, 1.0 equiv.), pinB-Bpin (0.24 mmol, 1.2 equiv.), $Cu_2(OH)_2CO_3$ (0.01 mmol, 0.05 equiv.), *t*-BuONa (0.3 mmol, 1.5 equiv.), D_2O or CD_3OD (1.2 mmol, 6.0 equiv.) in solvent (2.0 mL) heated at 100 ℃ for 1 h. Upon completion, the reaction mixture was cooled to room temperature, the crude boronate ester, THF (2.0 mL), and NaOH aqueous solution (3 M, 1.5 equiv.) were added to a 5.0 mL reaction tube. H_2O_2 (30% w/w in water, 1.5 equiv.) was added to the vessel dropwise at 0 ℃. The reaction mixture was then stirred at room temperature for 2-3 h until the boronate ester was completely consumed. Water (5.0 mL) was added, and the solution was extracted with EtOAc (2 × 10.0 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under vacuum. The residue was purified by column chromatography on silica gel (100-200 mesh) to afford

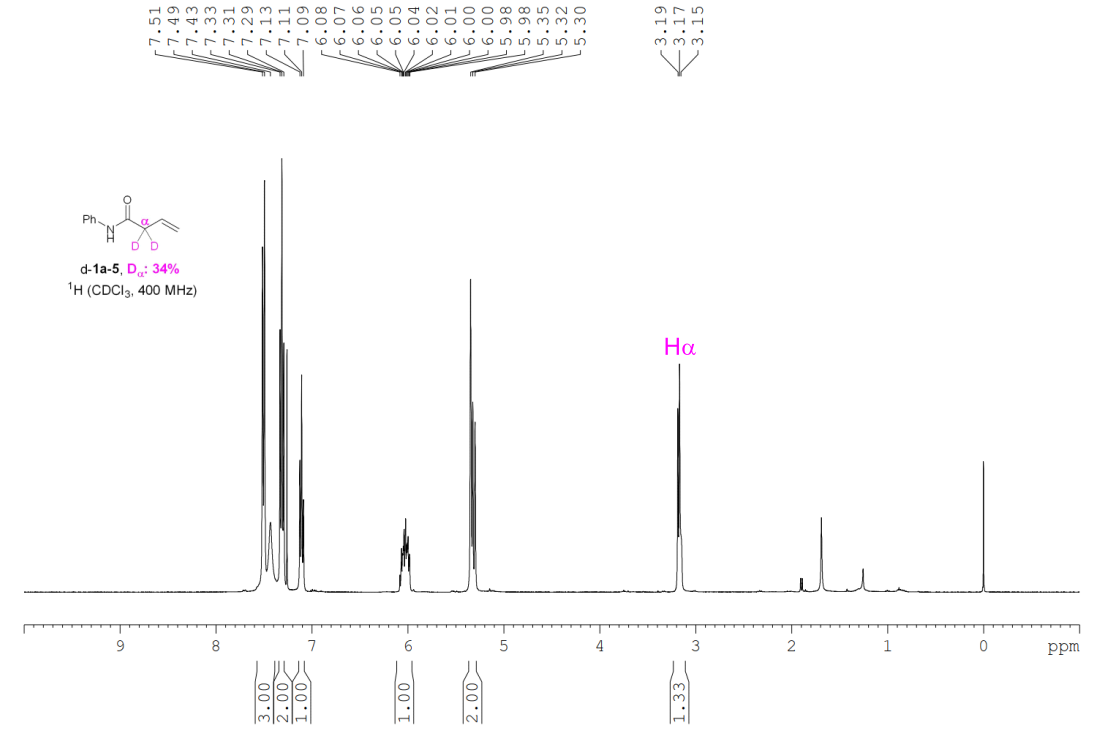
a corresponding product d-**4aa**.

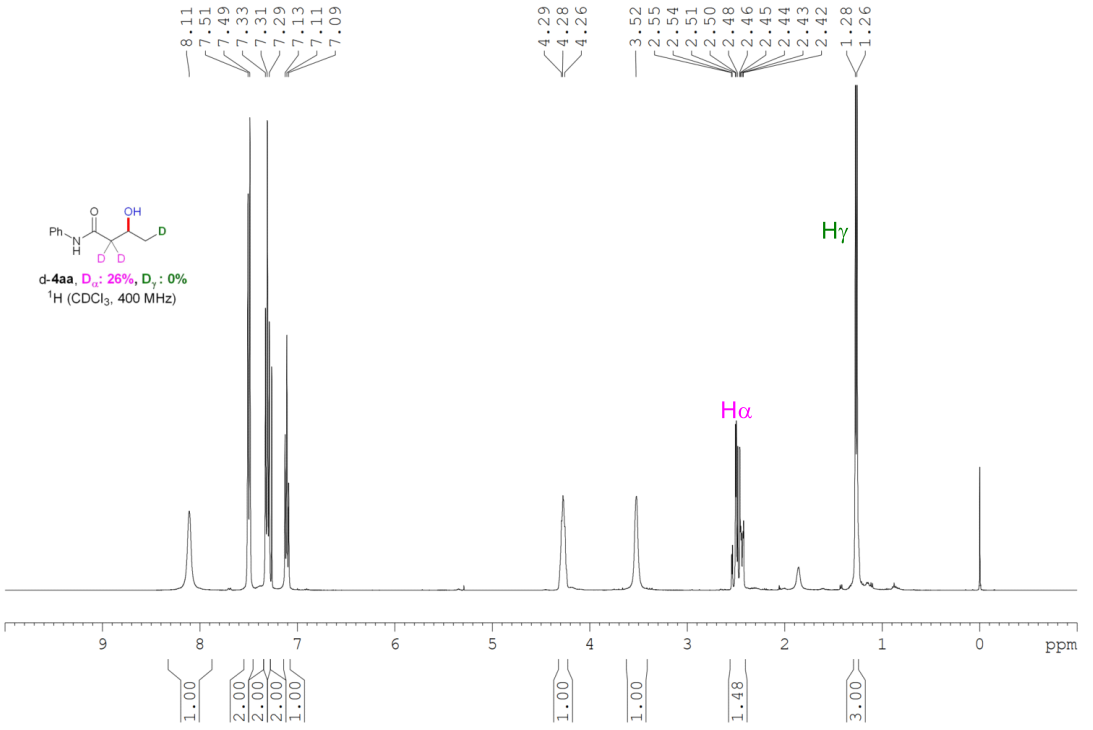


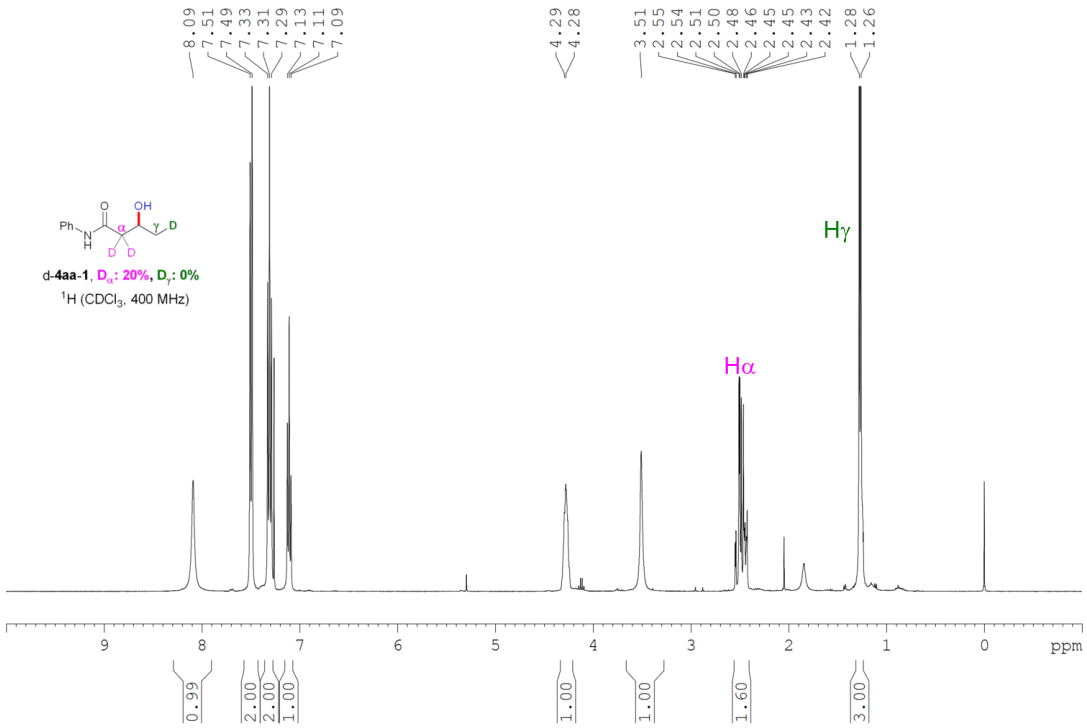


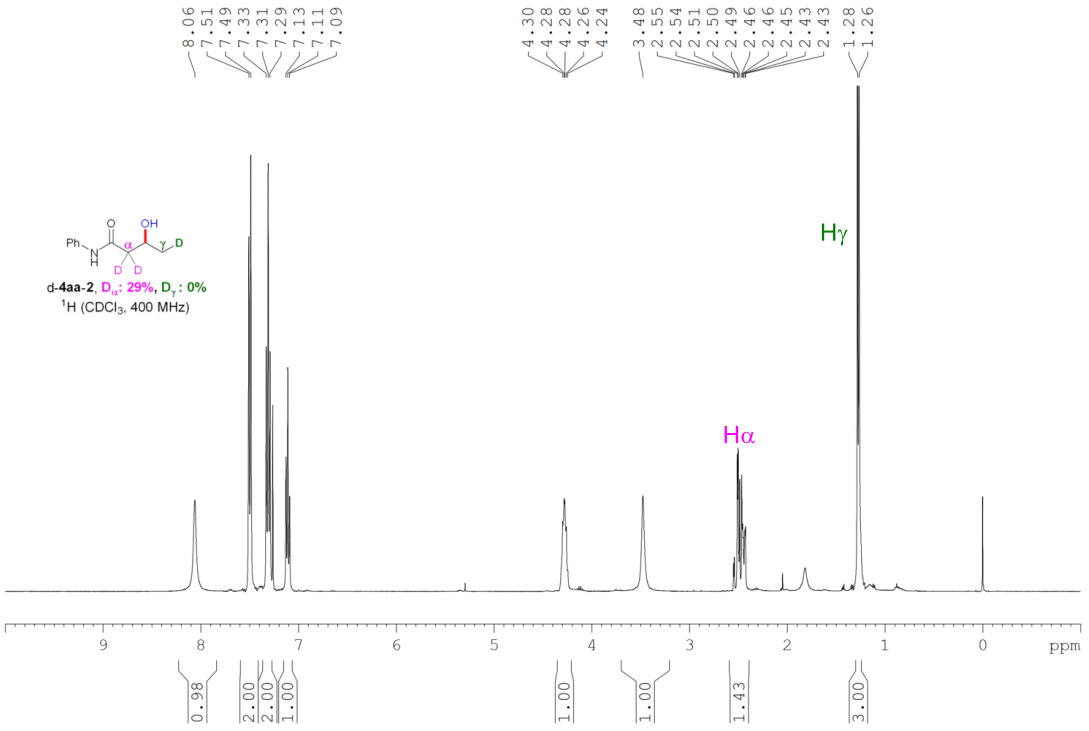

7.54
7.52
7.50
7.32
7.31
7.29
7.12
7.10
7.08
6.06
6.05
6.05
6.04
6.03
6.02
6.01
6.00
5.99
5.98
5.97
5.33
5.31
5.29
3.18
3.16
Ph
N
H
O
α
D
D
d-1a-2, Dα: 27%
1H (CDCl3, 400 MHz)
Hα
9
8
7
6
5
4
3
2
1
0
ppm
3.00
2.00
1.00
1.00
2.00
1.46

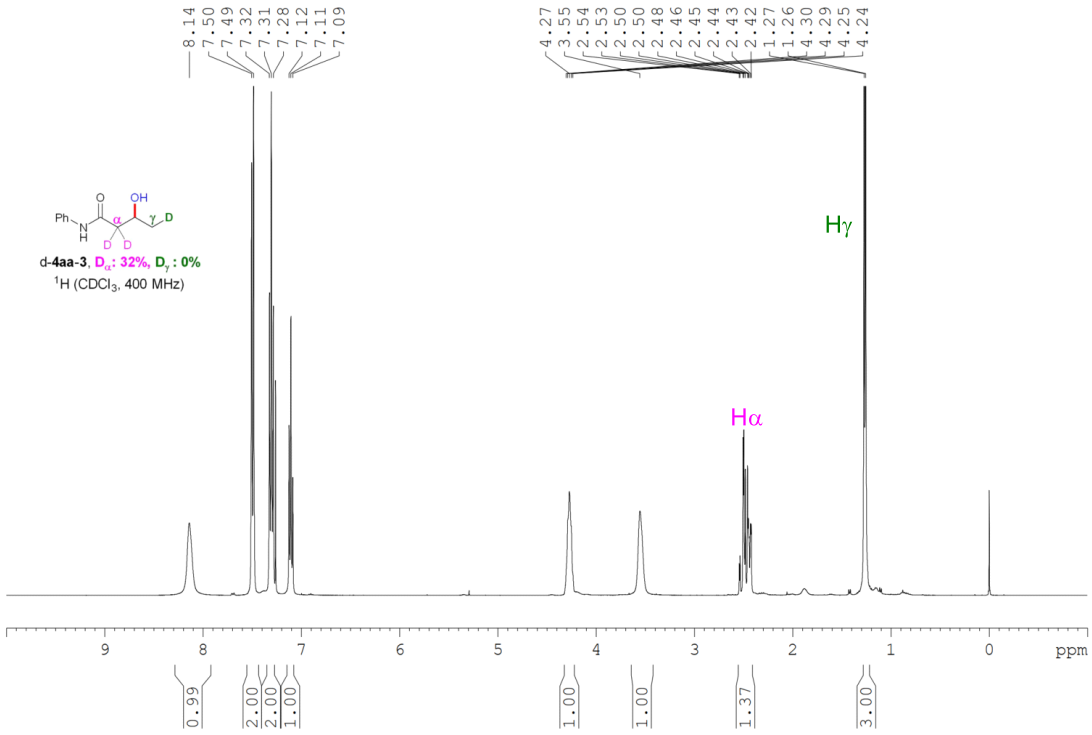

7.51
7.49
7.34
7.32
7.30
7.13
7.11
7.09
6.09
6.08
6.07
6.06
6.05
6.03
6.02
6.01
6.00
5.99
5.36
5.34
5.31
3.19
3.17
3.16
3.16
Ph
N
H
O
α
D
D
d-1a-4, Dα: 57%
1H (CDCl3, 400 MHz)
Hα
9
8
7
6
5
4
3
2
1
0
ppm
2.00
3.00
1.00
1.00
2.00
0.86

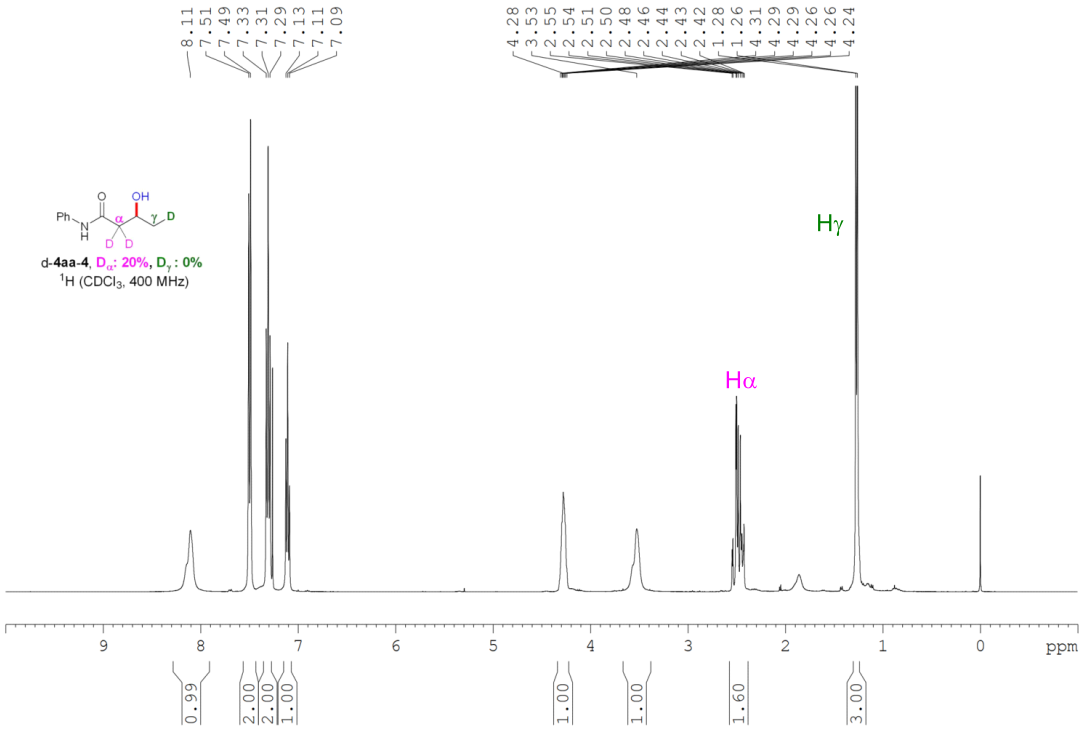

7.51
7.49
7.43
7.33
7.31
7.29
7.13
7.11
7.09
6.08
6.07
6.06
6.05
6.04
6.02
6.01
6.00
6.00
5.98
5.98
5.35
5.32
5.30
3.19
3.17
3.15
Ph
N
H
O
α
D
D
d-1a-5, Dα: 34%
1H (CDCl3, 400 MHz)
Hα
9
8
7
6
5
4
3
2
1
0
ppm
3.00
2.00
1.00
1.00
2.00
1.33

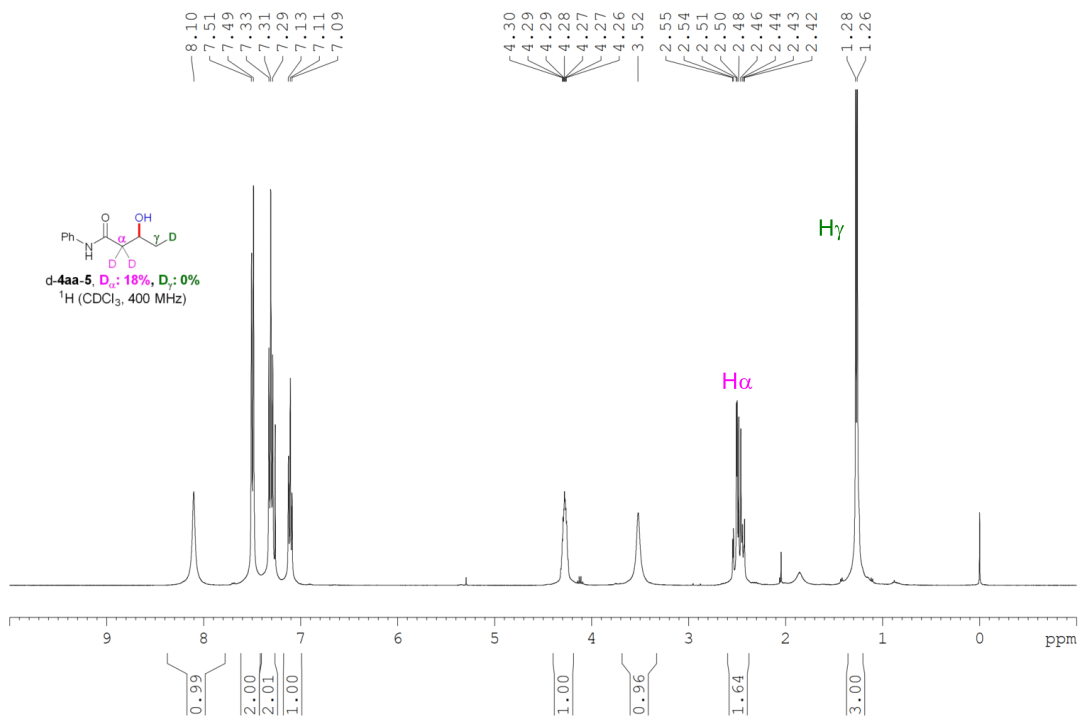

8.11
7.51
7.49
7.33
7.31
7.29
7.13
7.11
7.09
4.29
4.28
4.26
3.52
2.55
2.54
2.51
2.50
2.48
2.46
2.45
2.44
2.43
2.42
1.28
1.26
Ph
N
H
O
OH
D
D
D
d-4aa, Dα: 26%, Dγ: 0%
1H (CDCl3, 400 MHz)
Hγ
Hα
9
8
7
6
5
4
3
2
1
0
ppm
1.00
2.00
2.00
2.00
1.00
1.00
1.00
1.48
3.00

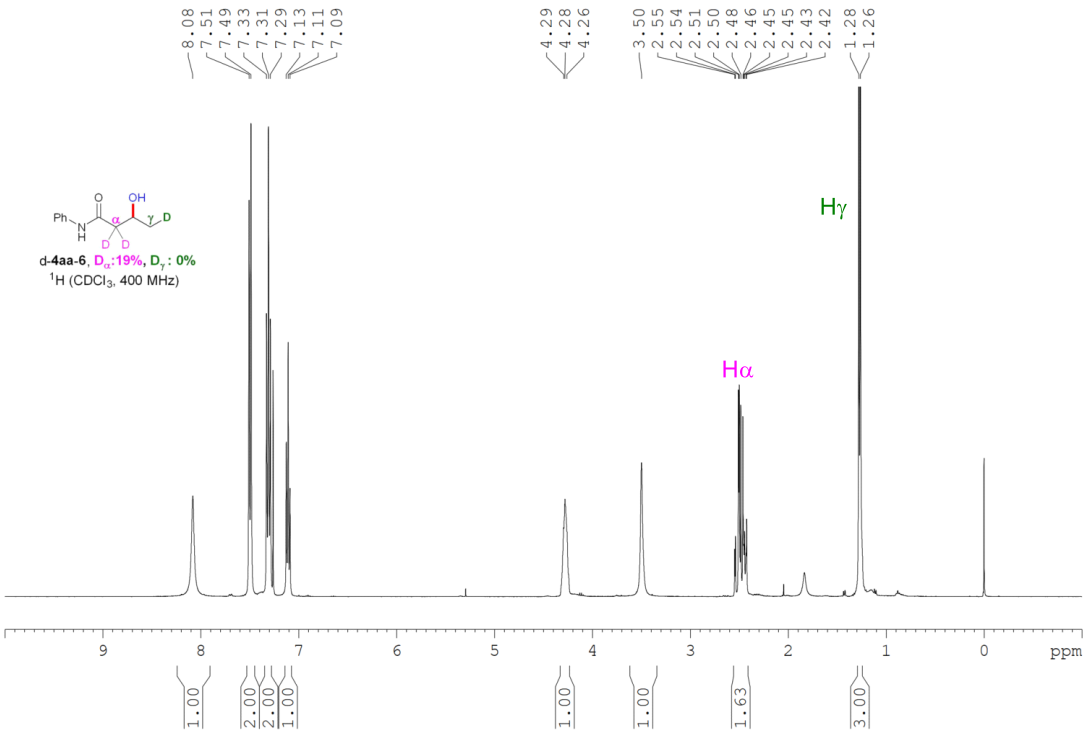

8.09
7.51
7.49
7.33
7.31
7.29
7.13
7.11
7.09
4.29
4.28
3.51
2.55
2.54
2.51
2.50
2.48
2.46
2.45
2.43
2.42
1.28
1.26
Hγ
Hα
d-4aa-1, Dα: 20%, Dγ: 0%
1H (CDCl3, 400 MHz)
ppm
0.99
2.00
2.00
1.00
1.00
1.00
1.60
3.00

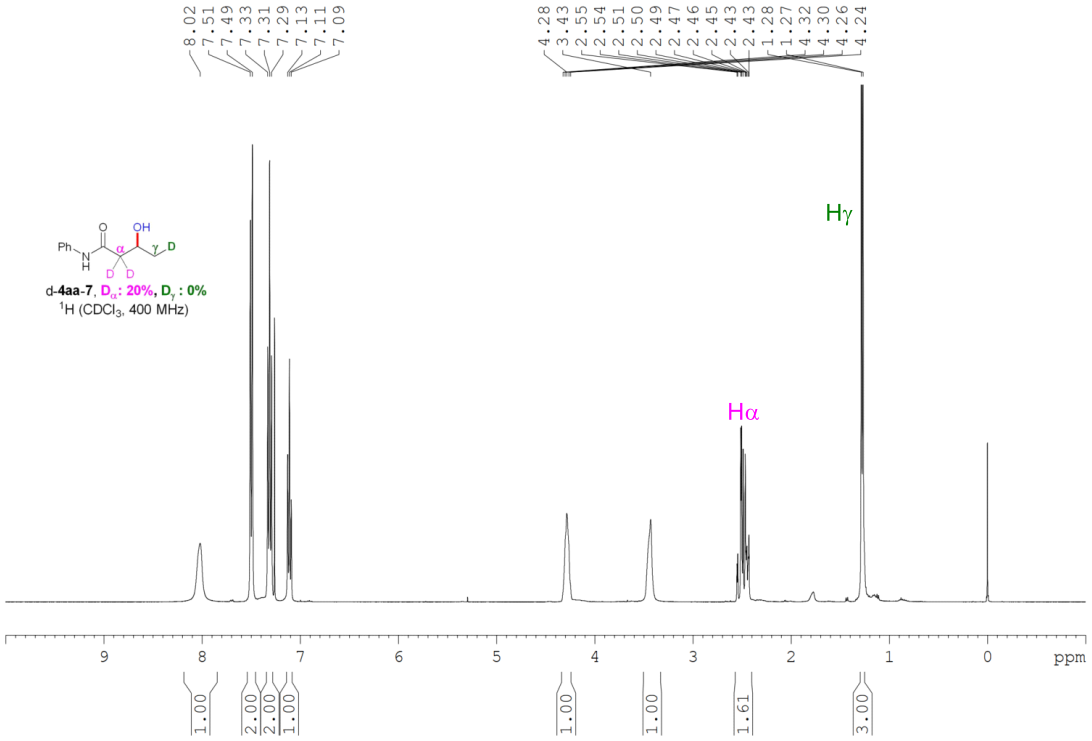

8.06
7.51
7.49
7.33
7.31
7.29
7.13
7.11
7.09
4.30
4.28
4.26
4.24
3.48
2.55
2.54
2.51
2.50
2.49
2.46
2.45
2.43
2.43
1.28
1.26
Hγ
Hα
d-4aa-2, Dα: 29%, Dγ: 0%
1H (CDCl3, 400 MHz)
ppm
0.98
2.00
2.00
1.00
1.00
1.00
1.43
3.00

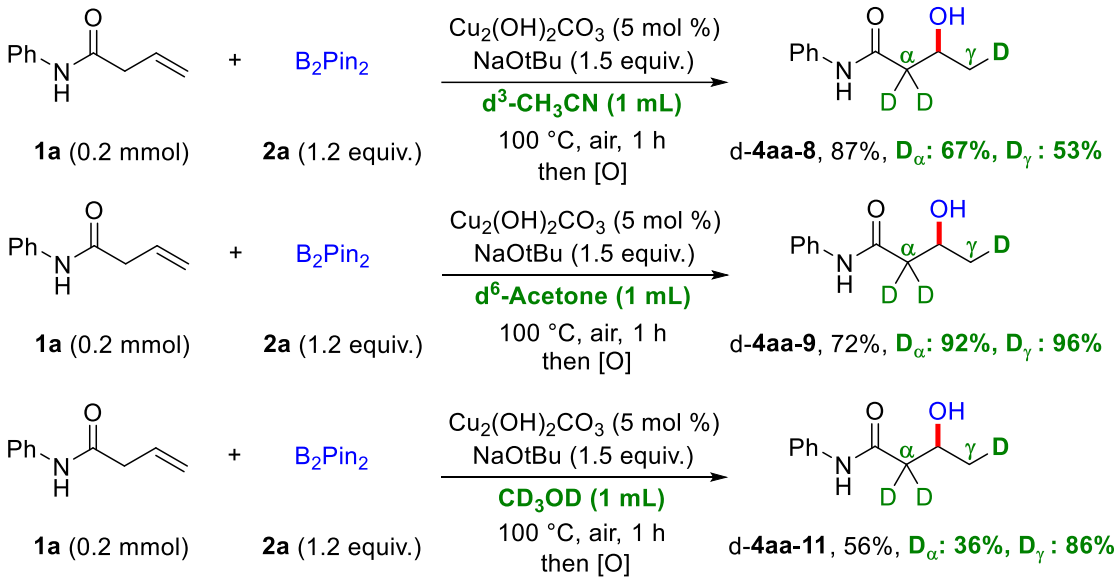

8.14
7.50
7.49
7.32
7.31
7.28
7.12
7.11
7.09
4.27
3.55
2.54
2.53
2.50
2.50
2.48
2.46
2.45
2.44
2.43
2.42
1.27
1.26
4.30
4.29
4.25
4.24
Hγ
Hα
d-4aa-3, Dα: 32%, Dγ: 0%
1H (CDCl3, 400 MHz)
9
8
7
6
5
4
3
2
1
0
ppm
0.99
2.00
2.00
1.00
1.00
1.00
1.37
3.00


8.11
7.51
7.49
7.33
7.31
7.29
7.13
7.11
7.09
4.28
3.53
2.55
2.54
2.51
2.50
2.48
2.46
2.44
2.43
2.42
1.28
1.26
4.31
4.29
4.29
4.26
4.26
4.24
Hγ
Hα
d-4aa-4, Dα: 20%, Dγ: 0%
1H (CDCl3, 400 MHz)
9
8
7
6
5
4
3
2
1
0
ppm
0.99
2.00
2.00
1.00
1.00
1.00
1.60
3.00


8.10
7.51
7.49
7.33
7.31
7.29
7.13
7.11
7.09
4.30
4.29
4.29
4.28
4.27
4.27
4.26
3.52
2.55
2.54
2.51
2.50
2.48
2.46
2.44
2.43
2.42
1.28
1.26
Hγ
Hα
d-4aa-5, Dα: 18%, Dγ: 0%
1H (CDCl3, 400 MHz)
9
8
7
6
5
4
3
2
1
0
ppm
0.99
2.00
2.01
1.00
1.00
0.96
1.64
3.00

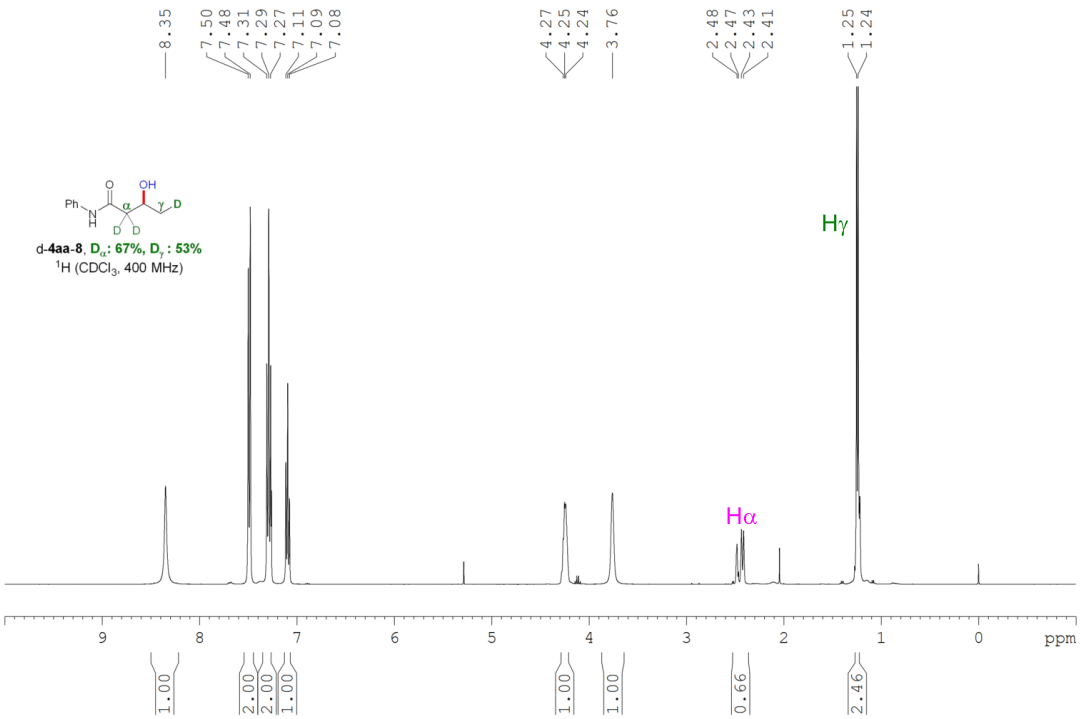

8.08
7.51
7.49
7.33
7.31
7.29
7.13
7.11
7.09
4.29
4.28
4.26
3.50
2.55
2.54
2.51
2.50
2.48
2.46
2.45
2.45
2.43
2.42
1.28
1.26
Hγ
Hα
d-4aa-6, Dα:19%, Dγ: 0%
1H (CDCl3, 400 MHz)
9
8
7
6
5
4
3
2
1
0
ppm
1.00
2.00
2.00
1.00
1.00
1.00
1.63
3.00

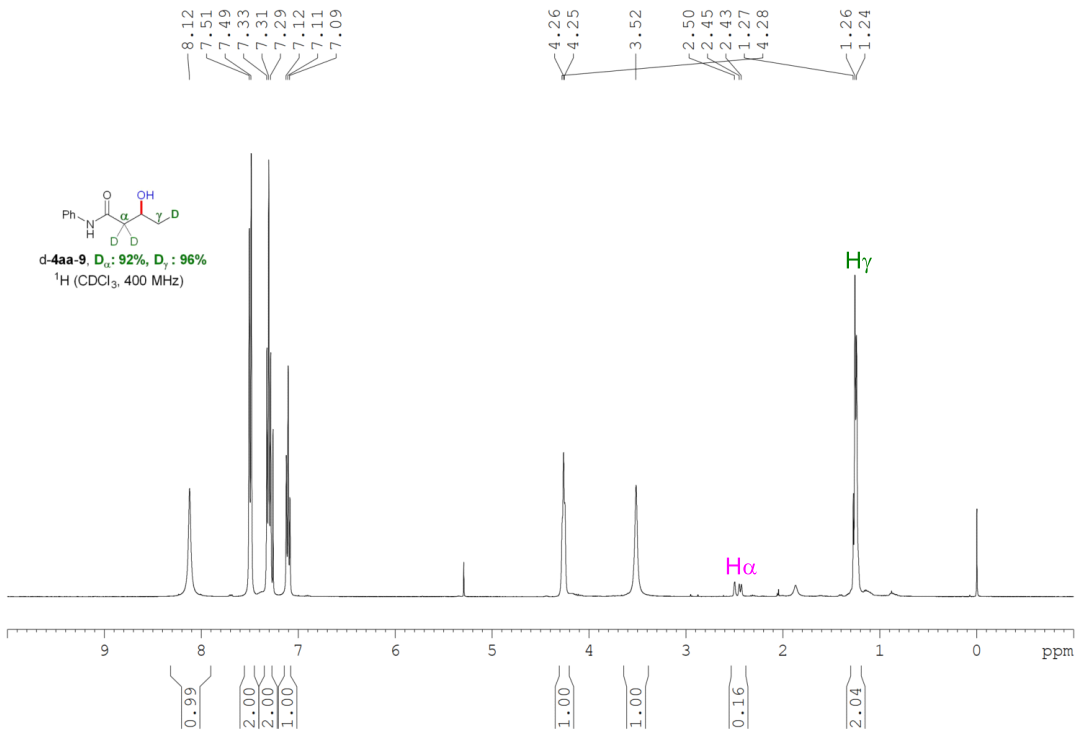


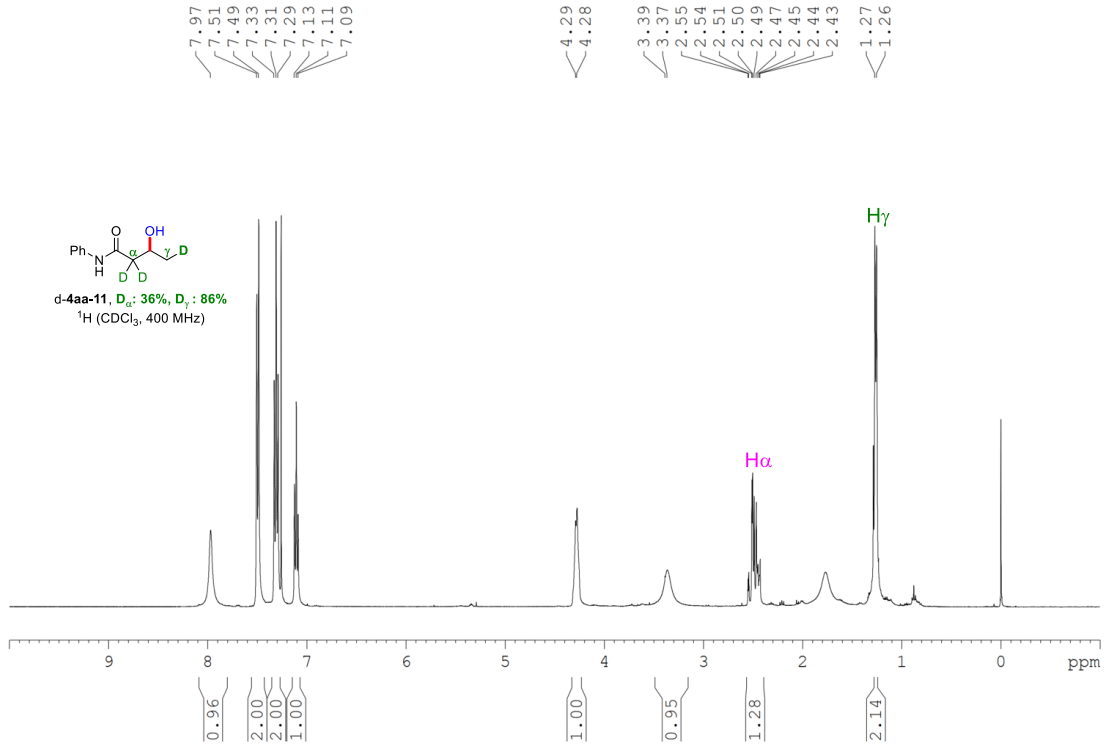


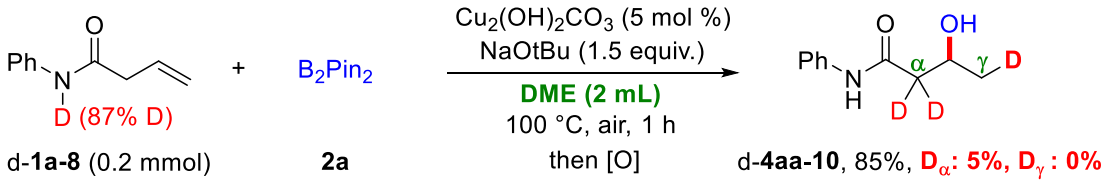
A Schlenk tube was equipped with a magnetic stir bar and charged with an alkene **1a** (0.2 mmol, 1.0 equiv.), pinB-Bpin (0.24 mmol, 1.2 equiv.), $Cu_2(OH)_2CO_3$ (0.01 mmol, 0.05 equiv.), *t*-BuONa (0.2 mmol, 1.5 equiv.) in d^3-CH_3CN, d^6-Acetone or CD_3OD (1.0 mL) heated at 100 °C for 1 h. Upon completion, the reaction mixture was cooled to room temperature, the crude boronate ester, THF (2.0 mL), and NaOH aqueous solution (3 M, 1.5 equiv.) were added to a 5.0 mL reaction tube. H_2O_2 (30% w/w in water, 1.5 equiv.) was added to the vessel dropwise at 0 ºC. The reaction mixture was then stirred at room temperature for 2-3 h until the boronate ester was completely consumed. Water (5.0 mL) was added, and the solution was extracted with EtOAc (2 × 10.0 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under vacuum. The

residue was purified by column chromatography on silica gel (100-200 mesh) to afford a corresponding product d-**4aa**





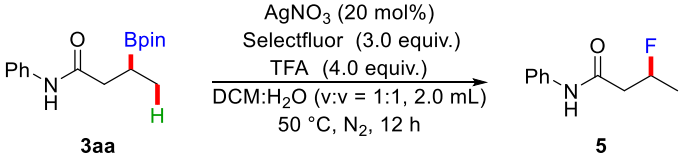




d-**1a-8** (0.2 mmol) **2a** d-**4aa-10**, 85%, D_α: 5%, D_γ : 0%

A Schlenk tube was equipped with a magnetic stir bar and charged with an alkene d-**1a-8** (0.2 mmol, 1.0 equiv.), pinB-Bpin (0.24 mmol, 1.2 equiv.), $Cu_2(OH)_2CO_3$ (0.01 mmol, 0.05 equiv.), *t*-BuONa (0.3 mmol, 1.5 equiv.) in DME (2.0 mL) heated at 100 ℃ for 1 h. Upon completion, the reaction mixture was cooled to room temperature, the crude boronate ester, THF (2.0 mL), and NaOH aqueous solution (3 M, 1.5 equiv.) were added to a 5.0 mL reaction tube. H_2O_2 (30% w/w in water, 1.5 equiv.) was added to the vessel dropwise at 0 ℃. The reaction mixture was then stirred at room temperature for 2-3 h until the boronate ester was completely consumed. Water (5.0 mL) was added, and the solution was extracted with EtOAc (2 × 10.0 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under vacuum. The residue was purified by column chromatography on silica gel (100-200 mesh) to afford the product d-**4aa-10**.

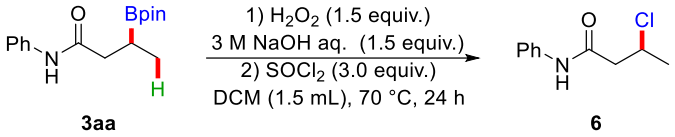
3.6 Procedures for the Transformations of Borylated Products



3aa **5**

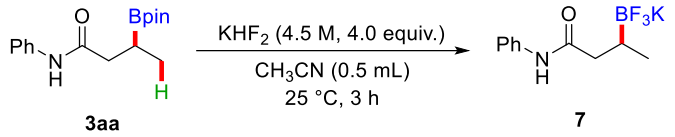
Procedure for Fluorination of Compound 3aa[2]: To a Schlenk tube containing a magnetic stir bar

were added compound **3aa** (0.2 mmol, 1.0 equiv.), $AgNO_3$ (0.04 mmol, 0.2 equiv.), and Selectfluor (0.6 mmol, 3.0 equiv.). The reaction vessel was evacuated and backfilled with N_2 (×3). DCM (1.0 mL), H_2O (1.0 mL), and TFA (0.8 mmol, 4.0 equiv.) were then added. The reaction mixture was stirred at 50 ºC for 12 h. After cooling to room temperature, the reaction was quenched by slow addition of saturated $NaHCO_3$ (10.0 mL), and the resulting mixture was extracted with EtOAc (3 × 10.0 mL). The combined organic layers were concentrated under vacuum and purified by silica gel chromatography (hexane:EtOAc = 5:1) to afford the product **5** as a white solid.



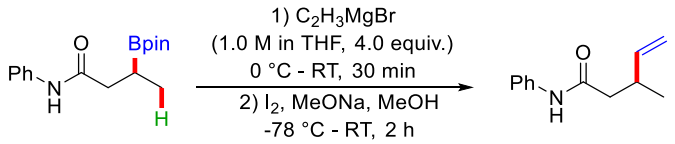
3aa **6**

Procedure for Chlorination of Compound 3aa[3]: To a Schlenk tube containing a magnetic stir bar were added compound **3aa** (0.2 mmol, 1.0 equiv.), THF (2.0 mL), and NaOH aqueous solution (3 M, 0.3 mmol, 1.5 equiv.) were added. H_2O_2 (30% w/w in water, 0.3 mmol, 1.5 equiv.) was added to the vessel dropwise at 0 °C. The reaction mixture was then stirred at room temperature for 2-3 h until the boronate ester was completely consumed. After the removal of solvent and adding $SOCl_2$ (0.6 mmol, 3.0 equiv.), DCM (1.5 mL) into the reaction mixture, the reaction mixture was stirred at 70 ºC for 24 h. After cooling to room temperature, the reaction was quenched by slow addition of saturated $NaHCO_3$ (10.0 mL), and the resulting mixture was extracted with DCM (2 × 10 mL). The combined organic layers were concentrated under vacuum and purified by silica gel chromatography (hexane:EtOAc = 5:1) to afford the product **6** as a light yellow solid.



3aa **7**

Procedure for Synthesis of Potassium Trifluoroborate Salt 7[4]: To a Schlenk tube containing a magnetic stir bar were added compound **3aa** (0.2 mmol, 1.0 equiv.), CH_3CN (0.5 mL), and saturated aq. KHF_2 (4.5 M, 1.6 mmol, 4.0 equiv.) was added. The reaction mixture was stirred at 25 °C for 3 h, concentrated, and azeotroped with EtOH (×3). The resulting material was then placed on the high vacuum for 6 h. The crude product was extracted with hot acetone, filtered and then concentrated. Et_2O (5 mL) was added to the crude material, and the mixture was sonicated for 30 min. After filtration, the trifluoroborate salt **7** was achieved as a white solid.

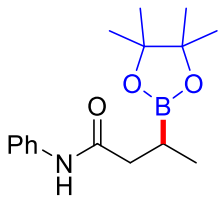


3aa **8**

Procedure for Synthesis of 8[5]: To a Schlenk tube containing a magnetic stir bar were added compound **3aa** (0.2 mmol, 1.0 equiv.), THF (1.5 mL), and vinylMgBr (1.0 M in THF, 0.8 mmol, 4.0 equiv.) was added at 0 °C. The resulting mixture was allowed to stir at same temperature for 2 h. Methanolic solution of I_2 (0.8 mmol, 4.0 equiv., 0.8 mL MeOH) was then introduced slowly to the

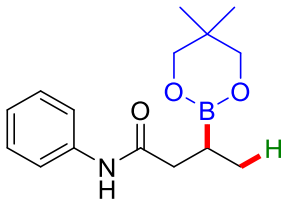
reaction mixture at -78 °C. The reaction was then allowed to stir at this temperature for additional 1 h. Methanolic solution of NaOMe (0.8 mmol, 4.0 equiv., 2.0 mL MeOH) was then added slowly at -78 °C. The resulting mixture was then warmed to room temperature and continued to stir at this temperature for 4 h. Saturated aqueous $Na_2S_2O_3$ (3.0 mL) was then added quench the reaction. After dilution with H_2O (20.0 mL), the mixture was extracted with Et_2O (3 × 10.0 mL). The combined organic phase was dried over anhydrous Na_2SO_4. After removal of the solvent, the residue was purified by silica gel chromatography (hexane:EtOAc = 6:1) to afford compound **8** as white solid.

4. Characterization Data of Products 3 and 4



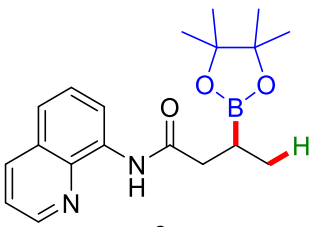
3aa

***N*-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butanamide** (**3aa**): white solid (hexane/DCM/EtOAc = 2/10/1, R_f = 0.4, yield: 80%, 2.0 mmol), mp 106-108 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01 (s, 1H), 7.53-7.51 (m, 2H), 7.27-7.23 (m, 2H), 7.05-7.01 (m, 1H), 2.51-2.38 (m, 2H), 1.50-1.41 (m, 1H), 1.25-1.24 (m, 12H), 1.05-1.03 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.7, 138.3, 128.8, 123.7, 119.7, 83.3, 41.9, 24.8, 24.7, 15.3, 14.2; ^{11}B NMR (128 MHz, $CDCl_3$) δ 34.03 (s, 1B); HRMS (ESI) calcd for $C_{16}H_{25}BNO_3^+$ ([M + H]$^+$) : 290.1922, found: 290.1909.



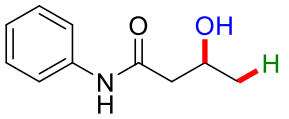
3ab

3-(5,5-dimethyl-1,3,2-dioxaborinan-2-yl)-*N*-phenylbutanamide (**3ab**): white solid (hexane/EtOAc = 1/2, R_f = 0.3, yield: 50%), mp 63-65 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56-7.48 (m, 3H), 7.31-7.27 (m, 2H), 7.08-7.04 (m, 1H), 3.62 (s, 4H), 2.49-2.35 (m, 2H), 1.41-1.33 (m, 1H), 1.03 (d, J = 7.61 Hz, 3H), 0.96 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.1, 138.2, 128.9, 123.8, 119.5, 72.0, 41.4, 31.7, 21.8, 15.7; ^{11}B NMR (128 MHz, $CDCl_3$) δ 30.40 (s, 1B); HRMS (ESI) calcd for $C_{15}H_{23}BNO_3^+$ ([M + H]$^+$) : 276.1766, found: 276.1769.



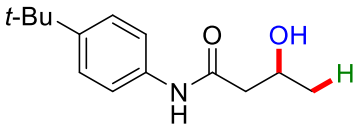
3va

***N*-(quinolin-8-yl)-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butanamide** (**3va**): white solid (DCM/EtOAc = 10/1, R_f = 0.2, yield: 49%), mp 84-85 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.78 (s, 1H), 8.79-8.78 (m, 2H), 8.15-8.13 (m, 1H), 7.53-7.42 (m, 3H), 2.76-2.68 (m, 1H), 2.61 (dd, J = 15.04 Hz, 7.26 Hz, 1H), 1.61-1.52 (m, 1H), 1.26 (s, 6H), 1.24 (s, 6H), 1.11 (d, J = 7.59 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.1, 138.2, 128.9, 123.8, 119.5, 72.0, 41.4, 31.7, 21.8, 15.7; ^{11}B NMR (128 MHz, $CDCl_3$) δ 34.60 (s, 1B); HRMS (ESI) calcd for $C_{19}H_{25}BN_2NaO_3^+$ ([M + Na]$^+$) : 363.1850, found: 363.1855.



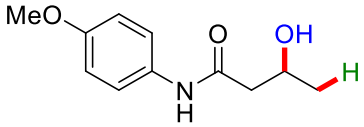
4aa

3-hydroxy-*N*-phenylbutanamide (**4aa**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 95%), mp 108-110 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (s, 0.98H), 7.50 (d, J = 7.71 Hz, 2H), 7.32 (t, J = 7.59 Hz, 2H), 7.11 (t, J = 7.37 Hz, 1H), 4.34-4.27 (m, 1H), 3.21-3.20 (m, 0.98H), 2.56-2.44 (m, 2H), 1.29 (d, J = 6.29 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.3, 137.5, 129.1, 124.5, 120.0, 65.0, 45.2, 23.0; HRMS (ESI) calcd for $C_{10}H_{13}NNaO_2^+$ ([M + Na]$^+$) : 202.0838, found: 202.0846.



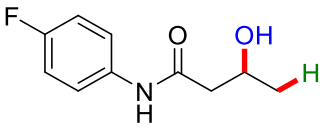
4ba

***N*-(4-(*tert*-butyl)phenyl)-3-hydroxybutanamide** (**4ba**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 92%), mp 90-92 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.78 (s, 1H), 7.51 (d, J = 8.68 Hz, 2H), 7.28 (t, J = 8.78 Hz, 2H), 4.72-4.71 (m, 0.97H), 4.11-4.05 (m, 1H), 2.42 (dd, J = 13.90 Hz, 7.40 Hz, 1H), 2.30 (dd, J = 13.82 Hz, 5.65 Hz, 1H), 1.25 (s, 9H), 1.12 (d, J = 6.23 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 169.9, 145.7, 137.1, 125.6, 119.3, 64.3, 46.9, 34.4, 31.6, 24.0; HRMS (ESI) calcd for $C_{14}H_{21}NNaO_2^+$ ([M + Na]$^+$) : 258.1465, found: 258.1472.



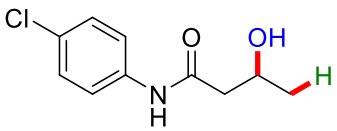
4ca

3-hydroxy-*N*-(4-methoxyphenyl)butanamide (**4ca**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 77%), mp 114-118 ℃; ^{1}H NMR (400 MHz, CD_3OD) δ 9.64 (s, 0.02H), 7.44-7.42 (m, 2H), 6.86-6.84 (m, 2H), 5.47 (s, 0.03), 4.27-4.19 (m, 1H), 3.75 (s, 3H), 2.51-2.39 (m, 2H), 1.24 (d, J = 6.29 Hz, 3H); ^{13}C NMR (100 MHz, d4-CD_3OD) δ 170.7, 165.5, 131.2, 121.7, 113.5, 64.6, 54.4, 45.5, 22.0; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_3^+$ ([M + Na]$^+$) : 232.0944, found: 232.0946.



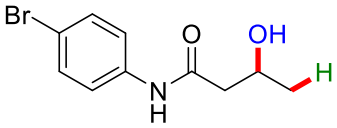
4da

***N*-(4-fluorophenyl)-3-hydroxybutanamide** (**4da**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 86%), mp 82-84 ℃; ^{1}H NMR (400 MHz, CD_3OD) δ 9.80 (s, 0.02H), 7.57-7.52 (m, 2H), 7.05-7.00 (m, 2H), 5.49-5.47 (m, 0.03), 4.28-4.20 (m, 1H), 2.53-2.41 (m, 2H), 1.24 (d, J = 6.31 Hz, 3H); ^{13}C NMR (100 MHz, d4-CD_3OD) δ 170.7, 159.26 (J = 242.26 Hz), 134.56 (J = 2.74 Hz), 121.7 (J = 7.84 Hz), 114.8 (J = 22.59 Hz), 64.6, 54.4, 45.5, 22.0; ^{19}F NMR (376 MHz, d4-CD_3OD) δ -120.55 (s, 1F); HRMS (ESI) calcd for $C_{10}H_{12}FNNaO_2^+$ ([M + Na]$^+$) : 220.0744, found: 220.0753.



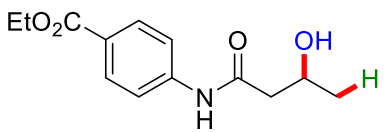
4ea

***N*-(4-chlorophenyl)-3-hydroxybutanamide** (**4ea**): white solid (hexane/EtOAc = 1/2, R_f = 0.2, yield: 91%), mp 78-81 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.99 (s, 0.96H), 7.65-7.61 (m, 2H), 7.35-7.31 (m, 2H), 4.74-4.73 (m, 0.95), 4.11-4.05 (m, 1H), 2.42 (dd, J = 13.88 Hz, 7.56 Hz, 1H), 2.32 (dd, J = 13.88 Hz, 5.47 Hz, 1H), 1.12 (d, J = 6.18 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 170.2, 138.6, 129.0, 127.0, 121.0, 64.2, 47.0, 24.0; HRMS (ESI) calcd for $C_{10}H_{12}ClNNaO_2^+$ ([M + Na]$^+$) : 236.0449, found: 236.0452.



4fa

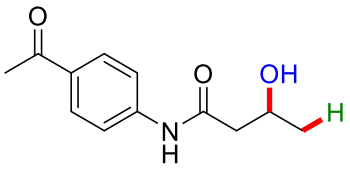
***N*-(4-bromophenyl)-3-hydroxybutanamide** (**4fa**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 86%), mp 89-90 ℃; ^{1}H NMR (400 MHz, CD_3OD) δ 9.84 (s, 0.02H), 7.51-7.49 (m, 2H), 7.42-7.40 (m, 2H), 5.48-5.48 (m, 0.03), 4.28-4.20 (m, 1H), 2.53-2.42 (m, 2H), 1.24 (d, J = 6.23 Hz, 3H); ^{13}C NMR (100 MHz, d4-CD_3OD) δ 171.0, 137.7, 131.3, 121.4, 116.0, 64.5, 45.8, 22.0; HRMS (ESI) calcd for $C_{10}H_{12}BrNNaO_2^+$ ([M + Na]$^+$) : 279.9944, found: 279.9948.



4ga

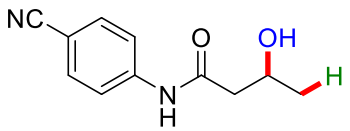
Ethyl 4-(3-hydroxybutanamido)benzoate (**4ga**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 80%), mp 82-84 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.74 (s, 1H), 7.97 (d, J = 8.94 Hz, 2H), 7.59 (d, J = 8.71 Hz, 2H), 4.38-4.30 (m, 3H), 3.66 (s, 1H), 2.58-2.46 (m, 2H), 1.38 (t, J = 7.11 Hz, 3H), 1.27 (d, J = 6.26 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.9, 166.3, 142.0, 130.7, 125.8, 119.1, 116.0,

64.9, 61.0, 45.4, 23.1, 14.3; HRMS (ESI) calcd for $C_{13}H_{17}NNaO_4^+$ ([M + Na]$^+$) : 274.1050, found: 274.1058.



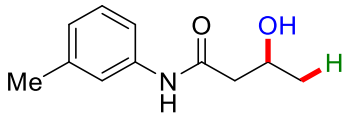
4ha

***N*-(4-acetylphenyl)-3-hydroxybutanamide** (**4ha**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 86%), mp 109-112 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 10.2 (s, 1H), 7.91 (d, J = 8.58 Hz, 2H), 7.74 (d, J = 8.77 Hz, 2H), 4.78-4.77 (m, 1H), 4.14-4.08 (m, 1H), 2.52 (s, 3H), 2.48-2.45 (m, 1H), 2.38 (dd, J = 13.92 HZ, 5.92 Hz, 1H), 1.14 (d, J = 6.18 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 196.9, 170.8, 144.1, 132.0, 129.9, 118.7, 64.2, 47.1, 26.8, 24.1; HRMS (ESI) calcd for $C_{12}H_{15}NNaO_3^+$ ([M + Na]$^+$) : 244.0944, found: 244.0954.



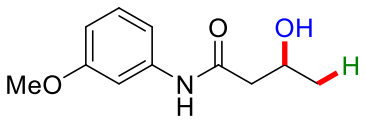
4ia

***N*-(4-cyanophenyl)-3-hydroxybutanamide** (**4ia**): white solid (hexane/EtOAc = 1/2, R_f = 0.3, yield: 75%), mp 70-71 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 10.30 (s, 1H), 7.81-7.74 (m, 4H), 4.78-4.77 (m, 1H), 4.13-4.07 (m, 1H), 2.49-2.36 (m, 2H), 1.13 (d, J = 6.16 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 171.0, 143.9, 133.7, 119.6, 119.4, 105.2, 64.2, 47.2, 24.1; HRMS (ESI) calcd for $C_{11}H_{12}N_2NaO_2^+$ ([M + Na]$^+$) : 227.0791, found: 227.0794.



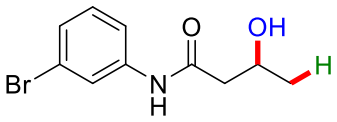
4ja

3-hydroxy-*N*-(*m*-tolyl)butanamide (**4ja**): white solid (hexane/EtOAc = 1/2, R_f = 0.3, yield: 88%), mp 79-81 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 (s, 1H), 7.34-7.33 (m, 1H), 7.28-7.26 (m, 1H), 7.19-7.15 (m, 1H), 6.92-6.90 (m, 1H), 4.26-4.34 (m, 1H), 3.73 (s, 1H), 2.52-2.39 (m, 2H), 2.30 (s, 3H), 1.24 (d, J = 6.27 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.8, 138.9, 137.5, 128.8, 125.3, 120.9, 117.3, 65.0, 45.1, 23.0, 21.4; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_2^+$ ([M + Na]$^+$) : 216.0995, found: 216.1003.



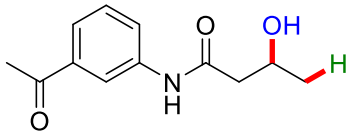
4ka

3-hydroxy-*N*-(3-methoxyphenyl)butanamide (**4ka**): white solid (hexane/EtOAc = 1/2, R_f = 0.2, yield: 77%), mp 35-37 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (s, 1H), 7.26-7.25 (m, 1H), 7.21-7.17 (m, 1H), 6.99-6.96 (m, 1H), 6.67-6.64 (m, 1H), 4.28-4.25 (m, 1H), 3.77 (s, 3H), 3.55-3.54 (m, 1H), 2.53-2.41 (m, 2H), 1.26 (d, J = 6.35 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.7, 160.1, 138.8, 129.7, 112.3, 110.2, 106.0, 65.0, 55.3, 45.2, 23.0; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_3^+$ ([M + Na]$^+$) : 232.0944, found: 232.0952.



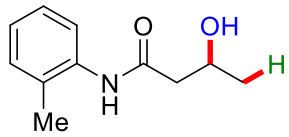
4la

***N*-(3-bromophenyl)-3-hydroxybutanamide** (**4la**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 91%), mp 107-111 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 10.03 (s, 1H), 7.99-7.98 (m, 1H), 7.49-7.47 (m, 1H), 7.27-7.19 (m, 2H), 4.75-4.74 (m, 1H), 4.11-4.05 (m, 1H), 2.42 (dd, J = 13.86 Hz, 7.64 Hz, 1H), 2.33 (dd, J = 14.00 Hz, 5.56 Hz, 1H) 1.13 (d, J = 6.25 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 175.2, 146.0, 135.8, 130.7, 126.7, 126.5, 122.9, 68.9, 51.8, 28.7; HRMS (ESI) calcd for $C_{10}H_{12}BrNNaO_2^+$ ([M + Na]$^+$) : 279.9944, found: 279.9948.



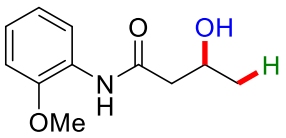
4ma

***N*-(3-acetylphenyl)-3-hydroxybutanamide** (**4ma**): white solid (EtOAc, R_f = 0.2, yield: 75%), mp 64-67 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.86 (s, 1H), 8.03-8.02 (m, 1H), 7.91-7.88 (m, 1H), 7.65-7.63 (m, 1H), 7.40-7.36 (m, 1H), 4.36-4.28 (m, 1H), 3.85 (s, 1H), 2.61-2.49 (m, 5H), 1.28 (d, J = 6.32 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.4, 171.0, 138.4, 137.5, 129.9, 124.8, 124.2, 119.3, 64.9, 45.3, 26.7, 23.1; HRMS (ESI) calcd for $C_{12}H_{15}NNaO_3^+$ ([M + Na]$^+$) : 244.0944, found: 244.0952.



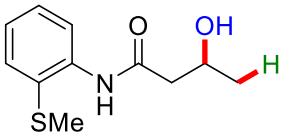
4na

3-hydroxy-*N*-(*o*-tolyl)butanamide (**4na**): white solid (hexane/EtOAc = 1/2, R_f = 0.2, yield: 91%), mp 83-84 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (s, 1H), 7.74-7.12 (m, 1H), 7.18-7.14 (m, 2H), 7.06-7.03 (m, 1H), 4.23-4.20 (m, 1H), 3.67 (s, 1H), 2.54-2.41 (m, 2H), 2.21 (s, 3H), 1.25 (d, J = 6.26 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ170.7, 135.5, 130.4, 129.5, 126.6, 125.2, 123.3, 64.9, 44.9, 23.1, 17.8; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_2^+$ ([M + Na]$^+$) : 216.0995, found: 216.1003.



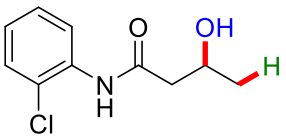
4oa

3-hydroxy-*N*-(2-methoxyphenyl)butanamide (**4oa**): white solid (hexane/EtOAc = 1/2, R_f = 0.2, yield: 82%), mp 51-52 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.33-8.30 (m, 1H), 8.16 (s, 1H), 7.06-7.02 (m, 1H), 6.96-6.92 (m, 1H), 6.88-6.85 (m, 1H), 4.30-4.26 (m, 1H), 3.86 (s, 3H), 3.69 (s, 1H), 2.57-2.46 (m, 2H), 1.27 (d, J = 6.28 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ170.4, 147.9, 127.3, 123.9, 121.0, 120.1, 110.0, 64.8, 55.7, 45.4, 22.8; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_3^+$ ([M + Na]$^+$) : 232.0944, found: 232.0953.



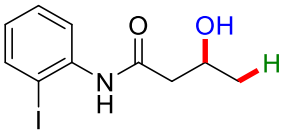
4pa

3-hydroxy-*N*-(2-(methylthio)phenyl)butanamide (**4pa**): colorless oil (hexane/EtOAc = 4/1, R_f = 0.2, yield: 90%); ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.40 (s, 1H), 7.59-7.56 (m, 1H), 7.35-7.33 (m, 1H), 7.19-7.16 (m, 2H), 4.95 (s, 1H), 4.09-4.03 (m, 1H), 2.47-2.35 (m, 5H), 1.15 (d, J = 6.13 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 170.2, 136.4, 131.9, 128.1, 126.1, 126.0, 125.2, 64.1, 46.2, 23.8, 16.0; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_2S^+$ ([M + Na]$^+$) : 248.0716, found: 248.0720.



4qa

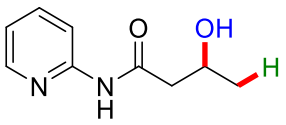
***N*-(2-chlorophenyl)-3-hydroxybutanamide** (**4qa**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 87%), mp 71-72 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.50 (s, 1H), 8.33-8.31 (m, 1H), 7.36-7.34 (m, 1H), 7.27-7.23 (m, 1H), 7.05-7.01 (m, 1H), 4.34-4.27 (m, 1H), 3.40 (s, 1H), 2.62-2.50 (m, 2H), 1.30 (d, J = 6.28 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 134.5, 129.0, 127.6, 124.8, 123.1, 122.0, 64.8, 45.5, 23.1; HRMS (ESI) calcd for $C_{10}H_{12}ClNNaO_2^+$ ([M + Na]$^+$) : 236.0449, found: 236.0457.



4ra

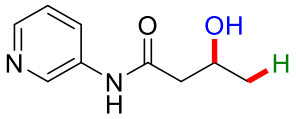
3-hydroxy-*N*-(2-iodophenyl)butanamide (**4ra**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 82%), mp 73-74 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14-8.10 (m, 2H), 7.79-7.76 (m, 1H), 7.35-7.30 (m, 1H), 6.86-6.82 (m, 1H), 4.35-4.29 (m, 1H), 3.36 (s, 1H), 2.62-2.51 (m, 2H), 1.30 (d, J = 6.72 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 138.9, 138.2, 129.1, 126.2, 122.7, 90.3, 64.7, 45.4,

23.1; HRMS (ESI) calcd for $C_{10}H_{12}INNaO_2^+$ ([M + Na]$^+$) : 327.9805, found: 327.9811.



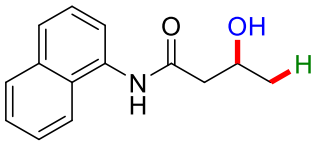
4sa

3-hydroxy-*N*-(pyridin-2-yl)butanamide (**4sa**): white solid (hexane/EtOAc = 1/4, R_f = 0.2, yield: 52%), mp 62-65 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 10.33 (s, 1H), 8.30-8.28 (m, 1H), 8.10-8.08 (m, 1H), 7.77-7.73 (m, 1H), 7.09-7.06 (m, 1H), 4.78-4.77 (m, 1H), 4.13-4.04 (m, 1H), 2.54-2.49 (m, 1H), 2.42 (dd, J = 14.19 Hz, 5.31 Hz, 1H), 1.12 (d, J = 6.20 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 171.0, 152.4, 148.3, 138.5, 119.6, 113.8, 64.1, 46.5, 23.9; HRMS (ESI) calcd for $C_9H_{12}N_2NaO_2^+$ ([M + Na]$^+$) : 203.0791, found: 203.0800.



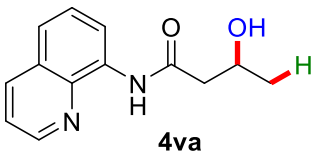
4ta

3-hydroxy-*N*-(pyridin-3-yl)butanamide (**4ta**): white solid (EtOAc/MeOH = 20/1, R_f = 0.4, yield: 53%), mp 63-66 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78 (s, 1H), 8.56-8.55 (m, 1H), 8.31-8.30 (m, 1H), 8.18-8.16 (m, 1H), 7.28-7.25 (m, 1H), 4.36-4.28 (m, 1H), 3.68 (s, 1H), 2.60-2.48 (m, 2H), 1.30 (d, J = 6.37 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.0, 144.8, 140.9, 135.0, 127.4, 123.9, 64.8, 45.3, 23.3; HRMS (ESI) calcd for $C_9H_{12}N_2NaO_2^+$ ([M + Na]$^+$) : 203.0791, found: 203.0789.



4ua

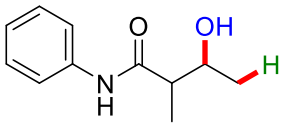
3-hydroxy-*N*-(naphthalen-1-yl)butanamide (**4ua**): white solid (hexane/EtOAc = 1/2, R_f = 0.2, yield: 80%), mp 108-109 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.90 (s, 1H), 8.10-8.07 (m, 1H), 7.93-7.91 (m, 1H), 7.75-7.71 (m, 2H), 7.56-7.46 (m, 3H), 4.93-4.92 (m, 1H), 4.20-4.14 (m, 1H), 2.64-2.59 (m, 1H), 2.53-2.52 (m, 1H), 1.21 (d, J = 6.21 Hz, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 170.8, 134.2, 134.1, 128.6, 128.1, 126.4, 126.2, 126.0, 125.5, 123.1, 121.9, 64.4, 46.4, 24.1; HRMS (ESI) calcd for $C_{14}H_{15}NNaO_2^+$ ([M + Na]$^+$) : 252.0995, found: 252.1002.



4va

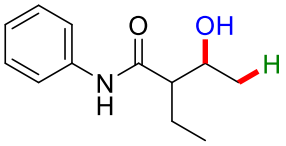
3-hydroxy-*N*-(quinolin-8-yl)butanamide (**4va**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 78%), mp 64-65 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.95 (s, 1H), 8.79-8.78 (m, 1H), 8.74-8.72 (m, 1H), 8.16-8.13 (m, 1H), 7.54-7.49 (m, 2H), 7.46-7.43 (m, 1H), 4.42-4.35 (m, 1H), 3.86 (s, 1H),

2.76-2.64 (m, 2H), 1.32 (d, J = 6.23 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.1, 148.3, 138.3, 136.4, 134.0, 127.9, 127.3, 121.9, 121.6, 116.8, 64.9, 45.5, 22.7; HRMS (ESI) calcd for $C_{13}H_{14}N_2NaO_2^+$ ([M + Na]$^+$) : 253.0947, found: 253.0955.



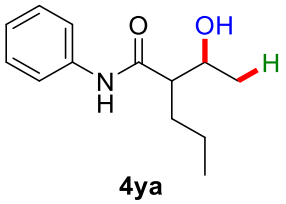
4wa

3-hydroxy-2-methyl-*N*-phenylbutanamide (**4wa**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 59%, dr = 1.7:1), mp 120-121 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.81-9.76 (m, 1H), 7.64-7.59 (m, 2H), 7.30-7.25 (m, 2H), 7.04-6.99 (m, 1H), 4.73-4.70 (m, 1H), 3.83-3.67 (m, 1H), 2.44-2.33 (m, 1H), 1.14-1.01 (m, 6H); ^{13}C NMR (100 MHz, d6-DMSO) δ 174.0, 139.6, 129.0, 123.5, 119.7, 68.6, 49.1, 21.9, 14.7; HRMS (ESI) calcd for $C_{11}H_{15}NNaO_2^+$ ([M + Na]$^+$) : 216.0995, found: 216.1001.



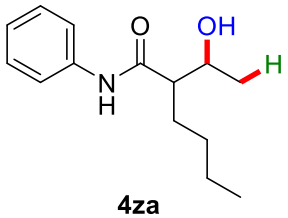
4xa

2-ethyl-3-hydroxy-*N*-phenylbutanamide (**4xa**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 44%, dr = 1.2:1), mp 90-92 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.04-8.04 (m, 1H), 7.53-7.51 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.14-3.97 (m, 1H), 3.13-2.92 (m, 1H), 2.28-2.23 (m, 1H), 1.91-1.78 (m, 1H), 1.74-1.55 (m, 1H), 1.30-1.21 (m, 3H), 1.02-0.98 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.6, 137.6, 128.9, 124.4, 120.2, 68.2, 56.5, 21.9, 20.0, 11.9; HRMS (ESI) calcd for $C_{12}H_{17}NNaO_2^+$ ([M + Na]$^+$) : 230.1151, found: 230.1159.



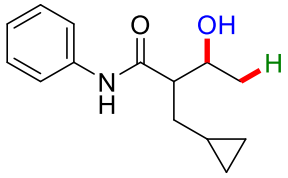
4ya

2-(1-hydroxyethyl)-*N*-phenylpentanamide (**4ya**): white solid (hexane/EtOAc = 1/2, R_f = 0.3, yield: 52%, dr = 1.4:1), mp 76-77 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.83-9.77 (m, 1H), 7.64-7.59 (m, 2H), 7.29-7.25 (m, 2H), 7.04-6.99 (m, 1H), 4.72-4.67 (m, 1H), 3.81-3.60 (m, 1H), 2.35-2.26 (m, 1H), 1.70-1.30 (m, 2H), 1.28-1.18 (m, 2H), 1.11-1.06 (m, 3H), 0.89-0.85 (m, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 173.5, 139.8, 129.0, 123.3, 119.5, 68.0, 55.1, 30.9, 21.9, 20.8, 14.5; HRMS (ESI) calcd for $C_{13}H_{19}NNaO_2^+$ ([M + Na]$^+$) : 244.1308, found: 244.1314.



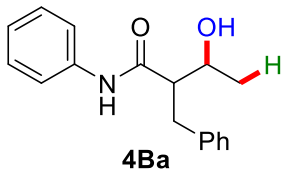
4za

2-(1-hydroxyethyl)-*N*-phenylhexanamide (**4za**): white solid (hexane/EtOAc = 1/1, R_f = 0.3, yield: 52%, dr = 1.4:1), mp 80-83 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.83-9.77 (m, 1H), 7.64-7.59 (m, 2H), 7.29-7.25 (m, 2H), 7.04-6.98 (m, 1H), 4.72-4.67 (m, 1H), 3.80-3.59 (m, 1H), 2.32-2.22 (m, 1H), 1.74-1.36 (m, 2H), 1.34-1.16 (m, 4H), 1.11-1.06 (m, 3H), 0.86-0.81 (m, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 173.5, 139.8, 129.0, 123.3, 119.5, 68.0, 55.3, 29.8, 28.3, 22.7, 21.9, 14.3; HRMS (ESI) calcd for $C_{14}H_{21}NNaO_2^+$ ([M + Na]$^+$) : 258.1465, found: 258.1469.



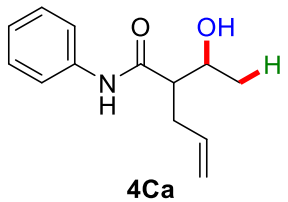
4Aa

2-(cyclopropylmethyl)-3-hydroxy-*N*-phenylbutanamide (**4Aa**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 35%, dr = 1.2:1), mp 98-99 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.86-9.79 (m, 1H), 7.62-7.57 (m, 2H), 7.27-7.23 (m, 2H), 7.01-6.96 (m, 1H), 4.67-4.63 (m, 1H), 3.79-3.57 (m, 1H), 2.43-2.33 (m, 1H), 1.58-1.21 (m, 2H), 1.07-1.04 (m, 3H), 0.63-0.56 (m, 1H), 0.36-0.26 (m, 2H), 0.03-0.06 (m, 2H); ^{13}C NMR (100 MHz, d6-DMSO) δ 173.5, 139.9, 128.9, 123.2, 119.6, 67.7, 55.6, 33.5, 21.8, 9.6, 5.1, 4.5; HRMS (ESI) calcd for $C_{14}H_{19}NNaO_2^+$ ([M + Na]$^+$) : 256.1308, found: 256.1316.



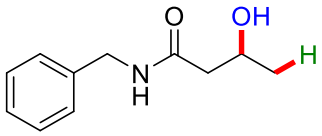
4Ba

2-benzyl-3-hydroxy-*N*-phenylbutanamide (**4Ba**): white solid (hexane/EtOAc = 2/1, R_f = 0.2, yield: 56%, dr = 2.2:1), mp 89-91 °C; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.67 (s, 1H), 7.51-7.45 (m, 2H), 7.24-6.95 (m, 8H), 4.95-4.82 (m, 0.98H), 3.91-3.71 (m, 1H), 3.07-2.58 (m, 3H), 1.19-1.12 (m, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 172.3, 140.6, 139.6, 129.2, 128.9, 128.5, 126.3, 123.3, 119.6, 67.9, 56.7, 34.0, 21.6; HRMS (ESI) calcd for $C_{17}H_{19}NNaO_2^+$ ([M + Na]$^+$) : 292.1308, found: 292.1316.



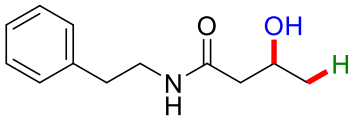
4Ca

2-(1-hydroxyethyl)-*N*-phenylpent-4-enamide (**4Ca**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 54%, dr = 1.3:1), mp 62-63 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.83-9.78 (m, 1H), 7.62-7.57 (m, 2H), 7.29-7.24 (m, 2H), 7.03-6.99 (m, 1H), 5.81-5.69 (m, 1H), 5.07-4.92 (m, 2H), 4.82-4.74 (m, 1H), 3.83-3.65 (m, 1H), 2.47-2.17 (m, 3H), 1.13-1.08 (m, 3H); ^{13}C NMR (100 MHz, d6-DMSO) δ 172.6, 139.7, 136.7, 129.0, 123.3, 119.6, 116.5, 67.7, 54.6, 32.8, 21.6; HRMS (ESI) calcd for $C_{13}H_{17}NNaO_2^+$ ([M + Na]$^+$) : 242.1151, found: 242.1156.



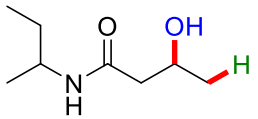
4Da

***N*-benzyl-3-hydroxybutanamide** (**4Da**): colorless oil (hexane/EtOAc = 1/1, R_f = 0.25, yield: 63%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35-7.30 (m, 2H), 7.28-7.25 (m, 3H), 6.37 (s, 1H), 4.43-4.41 (m, 2H), 4.22-4.14 (m, 1H), 3.78 (s, 1H), 2.38-2.25 (m, 2H), 1.20 (d, J = 6.27 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.2, 137.9, 128.7, 127.7, 127.6, 64.8, 43.9, 43.4, 22.8; HRMS (ESI) calcd for $C_{11}H_{16}NO_2^+$ ([M + H]$^+$) : 194.1176, found: 194.1178.



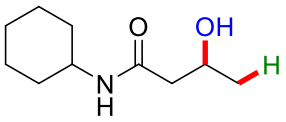
4Ea

3-hydroxy-*N*-phenethylbutanamide (**4Ea**): colorless oil (hexane/EtOAc = 1/1, R_f = 0.3, yield: 78%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34-7.30 (m, 2H), 7.26-7.19 (m, 3H), 6.06 (s, 1H), 4.18-4.10 (m, 1H), 3.82 (s, 1H), 3.56-3.51 (m, 2H), 2.83 (t, J = 7.04 Hz, 2H), 2.31-2.19 (m, 2H), 1.19 (d, J = 6.30 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.4, 138.6, 128.7, 128.6, 126.6, 64.8, 43.9, 40.4, 35.5, 22.7; HRMS (ESI) calcd for $C_{12}H_{18}NO_2^+$ ([M + H]$^+$) : 208.1332, found: 208.1332.



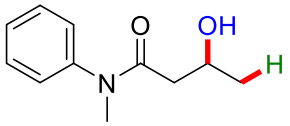
4Fa

***N*-(*sec*-butyl)-3-hydroxybutanamide** (**4Fa**): colorless oil (hexane/EtOAc = 1/1, R_f = 0.2, yield: 47%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.66 (s, 0.93H), 4.21-4.13 (m, 1H), 3.97-3.87 (m, 1.93H), 2.34-2.21 (m, 2H), 1.50-1.43 (m, 2H), 1.21 (d, J = 6.33 Hz, 3H), 1.13-1.12 (m, 3H), 0.92-0.88 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.7, 64.9, 46.5, 43.9, 29.6, 22.7, 20.3, 10.3; HRMS (ESI) calcd for $C_8H_{18}NO_2^+$ ([M + H]$^+$) : 160.1332, found: 160.1336.



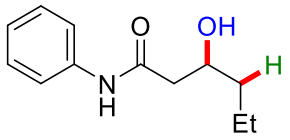
4Ga

***N*-cyclohexyl-3-hydroxybutanamide** (**4Ga**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 71%), mp 76-77 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.74 (s, 0.98H), 4.20-4.12 (m, 1H), 3.94 (s, 0.92H), 3.82-3.72 (m, 1H), 2.33-2.20 (m, 2H), 1.93-1.89 (m, 2H), 1.73-1.59 (m, 2H), 1.64-1.59 (m, 1H), 1.41-1.31 (m, 2H), 1.25-1.09 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.4, 64.9, 48.1, 43.9, 33.0, 25.4, 24.7, 22.7; HRMS (ESI) calcd for $C_{10}H_{20}NO_2^+$ ([M + H]$^+$) : 186.1489, found: 186.1490.



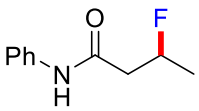
4Ha

3-hydroxy-*N*-methyl-N-phenylbutanamide (**4Ha**): colorless oil (hexane/EtOAc = 3/1, R_f = 0.2, yield: 87%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46-7.35 (m, 3H), 7.19-7.16 (m, 2H), 4.38 (s, 0.93H), 4.15-4.08 (m, 1H), 3.27 (s, 3H), 2.23-2.18 (m, 1H), 2.13-2.06 (m, 1H), 1.07 (d, J = 6.34 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.9, 143.3, 129.9, 128.1, 127.2, 64.5, 41.7, 37.0, 22.2; HRMS (ESI) calcd for $C_{11}H_{16}NO_2^+$ ([M + H]$^+$) : 194.1176, found: 194.1174.



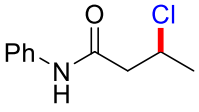
4Ja

3-hydroxy-*N*-phenylhexanamide (**4Ja**): white solid (hexane/EtOAc = 2/1, R_f = 0.3, yield: 23%), mp 142-145 ℃; ^{1}H NMR (400 MHz, d^6-DMSO) δ 9.81 (s, 0.97H), 7.60-7.58 (m, 2H), 7.29-7.25 (m, 2H), 7.03-6.99 (m, 1H), 4.66-4.65 (m, 1H), 3.96-3.89 (m, 1H), 2.41-2.32 (m, 2H), 1.43-1.28 (m, 4H), 0.87 (t, J = 7.04 Hz, 3H); ^{13}C NMR (100 MHz, d^6-DMSO) δ 170.3, 139.7, 129.0, 123.4, 119.5, 67.5, 45.5, 40.4, 18.7, 14.4; HRMS (ESI) calcd for $C_{12}H_{18}NO_2^+$ ([M + H]$^+$) : 208.1332, found: 208.1325.



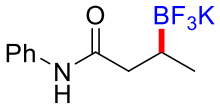
5

3-fluoro-*N*-phenylbutanamide (5): white solid (hexane/EtOAc = 5/1, R_f = 0.4, yield: 93%), mp 73-75 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (s, 1H), 7.52-7.50 (m, 2H), 7.31-7.27 (m, 2H), 7.12-7.08 (m, 1H), 5.26-5.06 (m, 1H), 2.75-2.54 (m, 2H), 1.46-1.38 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.9, 137.6, 128.9, 124.5, 120.1, 88.1 (J = 166.65 Hz), 45.0 (J = 21.77 Hz), 20.8 (J = 22.19 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ -171.40 (s, 1F); HRMS (ESI) calcd for $C_{10}H_{13}FNO^+$ ([M + H]$^+$) : 182.0976, found: 182.0974.



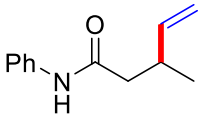
6

3-chloro-*N*-phenylbutanamide (6)[6]: light yellow solid (hexane/EtOAc = 5/1, R_f = 0.3, yield: 25%), mp 69-71 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52-7.50 (m, 2H), 7.35-7.31 (m, 3H), 7.14-7.11 (m, 1H), 4.60-4.52 (m, 1H), 2.81-2.71 (m, 2H), 1.64-1.62 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 137.4, 129.0, 124.6, 120.0, 54.0, 48.4, 25.2.



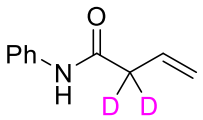
7

Potassium *N*-phenyl-3-(trifluoroborato)butanamide (7)[7]: white solid (yield: 91%), mp 120-122 °C; ^{1}H NMR (400 MHz, acetone-d^6) δ 8.98 (s, 0.4H), 7.70-7.68 (m, 2H), 7.24-7.21 (m, 2H), 6.98-6.94 (m, 1H), 2.43-2.38 (m, 1H), 2.09-2.07 (m, 1H), 0.92-0.86 (m, 4H); ^{13}C NMR (100 MHz, acetone-d^6) δ 174.6, 140.1, 128.3, 122.4, 119.0, 42.1, 20.3, 15.6; ^{11}B NMR (128 MHz, acetone-d^6) δ 5.43 (s, 1B); ^{19}F NMR (376 MHz, acetone-d^6) δ -147.22 (s, 1F).



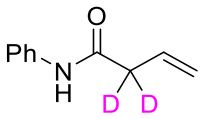
8

3-methyl-*N*-phenylpent-4-enamide (8)[8]: white solid (hexane/EtOAc = 6/1, R_f = 0.3, yield: 90%), mp 69-70 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (s, 1H), 7.51-7.49 (m, 2H), 7.30-7.26 (m, 2H), 7.10-7.06 (m, 1H), 5.86-5.77 (m, 1H), 5.09-4.98 (m, 2H), 2.83-2.72 (m, 1H), 2.38 (dd, J = 14.35 Hz, 7.36 Hz, 1H), 2.28 (dd, J = 14.20 Hz, 7.14 Hz, 1H), 1.09 (dd, J = 6.81 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.4, 142.6, 137.9, 128.9, 124.2, 120.0, 113.8, 44.6, 34.8, 19.7.



d-**1a**, D_α: 55%

α,α-2d-*N*-phenylbut-3-enamide (d-**1a**): white solid (hexane/EtOAc = 5/1, R_f = 0.4, yield: 30%), mp 59-60 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51-7.44 (m, 3H), 7.33-7.29 (m, 2H), 7.12-7.08 (m, 1H), 6.08-5.98 (m, 1H), 5.34-5.29 (m, 2H), 3.18-3.15 (m, 0.90H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.6, 137.6, 131.0, 129.0, 124.4, 120.6, 119.8, 42.7, 42.4 (t, J = 19.66 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 3.17 (s); HRMS (ESI) calcd for $C_{10}H_9D_2NNaO^+$ ([M + Na]$^+$) : 186.0858, found: 186.0854.



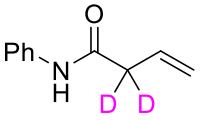
d-**1a-1**, D_α: 21%

α,α-2d-*N*-phenylbut-3-enamide (d-**1a-1**): white solid (hexane/EtOAc = 5/1, R_f = 0.4, yield: 50%), mp 59-60 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51-7.49 (m, 3H), 7.32-7.28 (m, 2H), 7.12-7.08 (m,

1H), 6.07-5.97 (m, 1H), 5.33-5.28 (m, 2H), 3.17-3.16 (m, 1.58H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.7, 137.7, 131.0, 129.0, 124.4, 120.5, 119.8, 42.7, 42.4 (t, J = 19.50 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 3.16 (s); HRMS (ESI) calcd for $C_{10}H_9D_2NNaO^+$ ([M + Na]$^+$) : 186.0858, found: 186.0855.

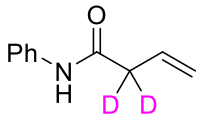
d-**1a-2**, D_α: 27%

α,α-2d-*N*-phenylbut-3-enamide (d-**1a-2**): white solid (hexane/EtOAc = 5/1, R_f = 0.4, yield: 57%), mp 59-60 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53-7.49 (m, 3H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 6.05-5.97 (m, 1H), 5.33-5.28 (m, 2H), 3.17-3.16 (m, 1.46H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.8, 137.7, 131.1, 131.0, 128.9, 124.4, 120.4, 119.8, 42.6, 42.3 (t, J = 19.59 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 3.17 (s); HRMS (ESI) calcd for $C_{10}H_9D_2NNaO^+$ ([M + Na]$^+$) : 186.0858, found: 186.0848.



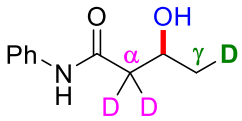
d-**1a-4**, D_α: 57%

α,α-2d-*N*-phenylbut-3-enamide (d-**1a-4**): white solid (hexane/EtOAc = 5/1, R_f = 0.4, yield: 17%), mp 59-60 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51-7.49 (m, 2H), 7.32-7.29 (m, 3H), 7.12-7.09 (m, 1H), 6.08-5.99 (m, 1H), 5.35-5.31 (m, 2H), 3.19-3.15 (m, 0.86H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.6, 137.6, 131.0, 129.0, 124.4, 120.7, 119.7, 42.7, 42.4 (t, J = 19.71 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 3.15 (s); HRMS (ESI) calcd for $C_{10}H_9D_2NNaO^+$ ([M + Na]$^+$) : 186.0858, found: 186.0855.



d-**1a-5**, D_α: 34%

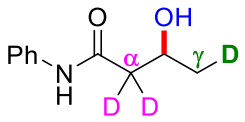
α,α-2d-*N*-phenylbut-3-enamide (d-**1a-5**): white solid (hexane/EtOAc = 5/1, R_f = 0.4, yield: 34%), mp 59-60 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51-7.43 (m, 3H), 7.33-7.29 (m, 2H), 7.12-7.08 (m, 1H), 6.08-5.97 (m, 1H), 5.34-5.29 (m, 2H), 3.18-3.15 (m, 1.33H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.6, 137.6, 131.08, 131.06, 129.0, 124.4, 120.6, 119.8, 42.7, 42.4 (t, J = 19.69 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 3.16 (s); HRMS (ESI) calcd for $C_{10}H_9D_2NNaO^+$ ([M + Na]$^+$) : 186.0858, found: 186.0850.



d-**4aa**, D_α: 26%, D_γ : 0%

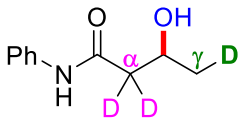
α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 53%), mp 109-110 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28

(m, 2H), 7.12-7.08 (m, 1H), 4.29-4.25 (m, 1H), 3.52 (s, 1H), 2.54-2.42 (m, 1.48H), 1.26 (d, J = 6.28 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.5, 120.1, 64.98, 64.95, 45.1, 44.8 (t, J = 19.18 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.49 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1134.



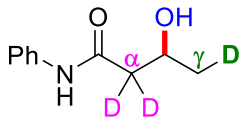
d-**4aa-1**, D_α: 20%, D_γ: 0%

α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-1**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 36%), mp 106-107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.29-4.27 (m, 1H), 3.50 (s, 1H), 2.54-2.42 (m, 1.60H), 1.27 (d, J = 6.30 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.57, 170.51, 137.5, 129.0, 124.5, 120.13, 120.10, 64.98, 64.95, 45.1, 44.8 (t, J = 20.43 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.50 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1133.



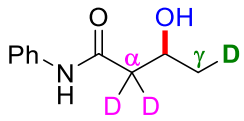
d-**4aa-2**, D_α: 29%, D_γ : 0%

α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-2**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 35%), mp 108-110 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.29 (m, 2H), 7.12-7.09 (m, 1H), 4.29-4.24 (m, 1H), 3.47 (s, 1H), 2.54-2.42 (m, 1.43H), 1.27 (d, J = 6.26 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.60, 170.53, 137.5, 129.0, 124.5, 120.14, 120.11, 64.98, 64.95, 45.1, 44.8 (t, J = 19.05 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.50 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + Na]$^+$) : 204.0964, found: 204.0955.



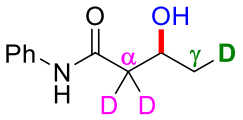
d-**4aa-3**, D_α: 32%, D_γ : 0%

α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-3**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 56%), mp 107-109 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.30-4.23 (m, 1H), 3.55 (s, 1H), 2.54-2.42 (m, 1.36H), 1.27 (d, J = 6.28 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.6, 137.5, 129.0, 124.5, 120.1, 64.98, 64.94, 45.1, 44.8 (t, J = 19.18 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.48 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1132.



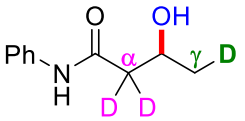
d-**4aa-4**, D_α: 20%, D_γ : 0%

α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-4**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 77%), mp 107-108 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.30-4.24 (m, 1H), 3.52 (s, 1H), 2.54-2.42 (m, 1.59H), 1.26 (d, *J* = 6.31 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.5, 120.1, 64.98, 64.95, 45.1, 44.8 (t, *J* = 19.71 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.49 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1137.



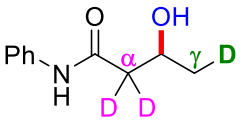
d-**4aa-5**, D_α: 18%, D_γ: 0%

α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-5**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 39%), mp 109-110 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.30-4.25 (m, 1H), 3.52 (s, 1H), 2.54-2.42 (m, 1.63H), 1.26 (d, *J* = 6.27 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.5, 120.1, 64.98, 64.95, 45.1, 44.8 (t, *J* = 19.15 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.49 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1136.



d-**4aa-6**, D_α: 19%, D_γ : 0%

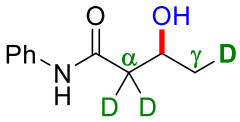
α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-6**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 49%), mp 106-108 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.29-4.25 (m, 1H), 3.49 (s, 1H), 2.54-2.42 (m, 1.62H), 1.27 (d, *J* = 6.28 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.5, 120.1, 64.98, 64.95, 45.1, 44.8 (t, *J* = 19.58 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.49 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1137.



d-**4aa-7**, D_α: 20%, D_γ : 0%

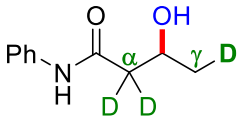
α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-7**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 41%), mp 107-108 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01 (s, 1H), 7.50-7.48 (m, 2H), 7.33-7.29 (m, 2H), 7.12-7.09 (m, 1H), 4.32-4.24 (m, 1H), 3.43 (s, 1H), 2.55-2.42 (m, 1.61H), 1.27 (d, *J*

= 6.28 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.5, 120.1, 64.98, 64.95, 45.1, 44.8 (t, J = 18.79 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.49 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + Na]$^+$) : 204.0964, found: 204.0954.



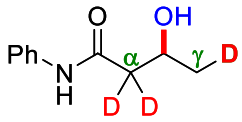
d-**4aa-8**, **D_α: 67%, D_γ : 53%**

Deuterated-3-hydroxy-*N*-phenylbutanamide (d-**4aa-8**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 87%), mp 106-107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.34 (s, 1H), 7.49-7.47 (m, 2H), 7.30-7.26 (m, 2H), 7.11-7.07 (m, 1H), 4.26-4.23 (m, 1H), 3.76 (s, 1H), 2.48-2.41 (m, 0.66H), 1.24 (d, J = 6.34 Hz, 2.46H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.6, 137.5, 129.0, 124.5, 120.18, 120.15, 64.94, 64.89, 64.85, 45.1-44.6 (m), 23.04, 23.00, 22.7 (t, J = 19.64 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.49 (s), 1.28 (s); HRMS (ESI) calcd for $C_{10}H_{10}D_3NNaO_2^+$ ([M + Na]$^+$) : 205.1027, found: 205.1025.



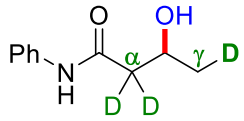
d-**4aa-9**, **D_α: 92%, D_γ : 96%**

Deuterated-3-hydroxy-*N*-phenylbutanamide (d-**4aa-9**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 72%), mp 106-108 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.50-7.48 (m, 2H), 7.32-7.28 (m, 2H), 7.12-7.08 (m, 1H), 4.27-4.25 (m, 1H), 3.51 (s, 1H), 2.49-2.42 (m, 0.15H), 1.27-1.24 (m, 2.04H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.5, 120.1, 64.8, 44.9-44.1 (m), 23.0, 22.7 (t, J = 19.32 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.46 (s), 1.27 (s); HRMS (ESI) calcd for $C_{10}H_{10}D_3NNaO_2^+$ ([M + Na]$^+$) : 205.1027, found: 205.1025.



d-**4aa-10**, **D_α: 5%, D_γ : 0%**

α,α-2d-3-hydroxy-*N*-phenylbutanamide (d-**4aa-10**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 85%), mp 104-106 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (s, 1H), 7.50-7.48 (m, 2H), 7.31-7.27 (m, 2H), 7.11-7.08 (m, 1H), 4.30-4.23 (m, 1H), 3.62 (s, 0.95H), 2.53-2.41 (m, 1.90H), 1.26 (d, J = 6.32 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.7, 137.6, 129.0, 124.5, 120.2, 64.9, 41.5, 44.8 (t, J = 19.45 Hz), 23.0; ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.45 (s); HRMS (ESI) calcd for $C_{10}H_{12}D_2NO_2^+$ ([M + H]$^+$) : 182.1145, found: 182.1128.

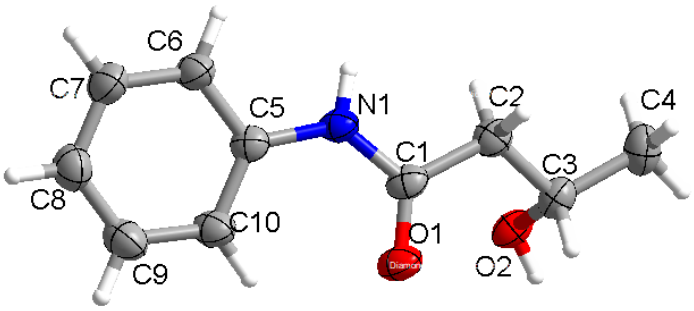


d-**4aa-11**, D_α: 36%, D_γ : 35%

Deuterated-3-hydroxy-*N*-phenylbutanamide (d-**4aa-11**): white solid (hexane/EtOAc = 1/1, R_f = 0.2, yield: 56%), mp 107-108 ℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (s, 0.96H), 7.50-7.48 (m, 2H), 7.32-7.29 (m, 2H), 7.12-7.08 (m, 1H), 4.29-4.27 (m, 1H), 3.37 (s, 0.95H), 2.55-2.42 (m, 1.28H), 1.26 (d, J = 6.52 Hz, 1.93H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.5, 137.5, 129.0, 124.4, 120.1, 64.9, 45.1, 44.8 (t, J = 20.87 Hz), 29.6, 23.0, 22.7 (t, J = 19.40 Hz); ^{2}H NMR (61 MHz, $CDCl_3$) δ 2.47 (s), 1.26 (s); HRMS (ESI) calcd for $C_{10}H_{10}D_3NNaO_2^+$ ([M + Na]$^+$) : 205.1027, found: 205.1024.

5. The Single Crystal X-ray Diffraction Study

The Single Crystal X-ray Diffraction Study of **4aa**



The structure of **4aa** (containing little solvent) was determined by the X-ray diffraction. Recrystallized from DCM/hexane. CCDC: 2242953 (**4aa**) contains the supplementary crystallographic data. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Table S9 Crystal data and structure refinement for CCDC: 2242953 (4aa) (displacement ellipsoids are drawn at the 30% probability level).

Identification code	20230207
Empirical formula	$C_{10}H_{13}NO_2$
Formula weight	179.21
Temperature/K	293(2)
Crystal system	monoclinic
Space group	C2/c
a/Å	20.5451(8)
b/Å	10.7614(4)
c/Å	9.2895(4)
α/°	90
β/°	97.545(4)
γ/°	90

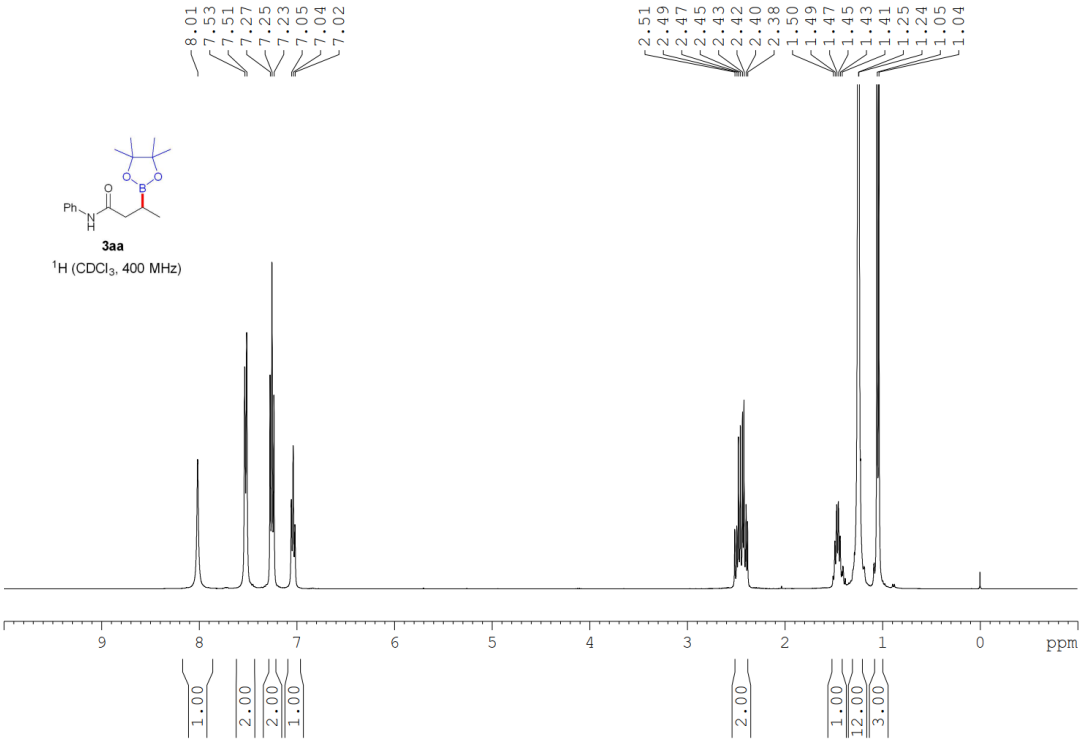
Volume/$Å^3$	2036.08(14)
Z	8
ρcalcg/cm^3	1.169
μ/mm^{-1}	0.663
F(000)	768.0
Crystal size/mm^3	0.17 × 0.13 × 0.1
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	8.684 to 134.098
Index ranges	-24 ≤ h ≤ 24, -12 ≤ k ≤ 12, -8 ≤ l ≤ 11
Reflections collected	6526
Independent reflections	1816 [R_{int} = 0.0323, R_{sigma} = 0.0263]
Data/restraints/parameters	1816/1/124
Goodness-of-fit on F^2	1.036
Final R indexes [I>=2σ (I)]	R1 = 0.0485, wR2 = 0.1327
Final R indexes [all data]	R1 = 0.0666, wR2 = 0.1519
Largest diff. peak/hole / e $Å^{-3}$	0.16/-0.18

6. References

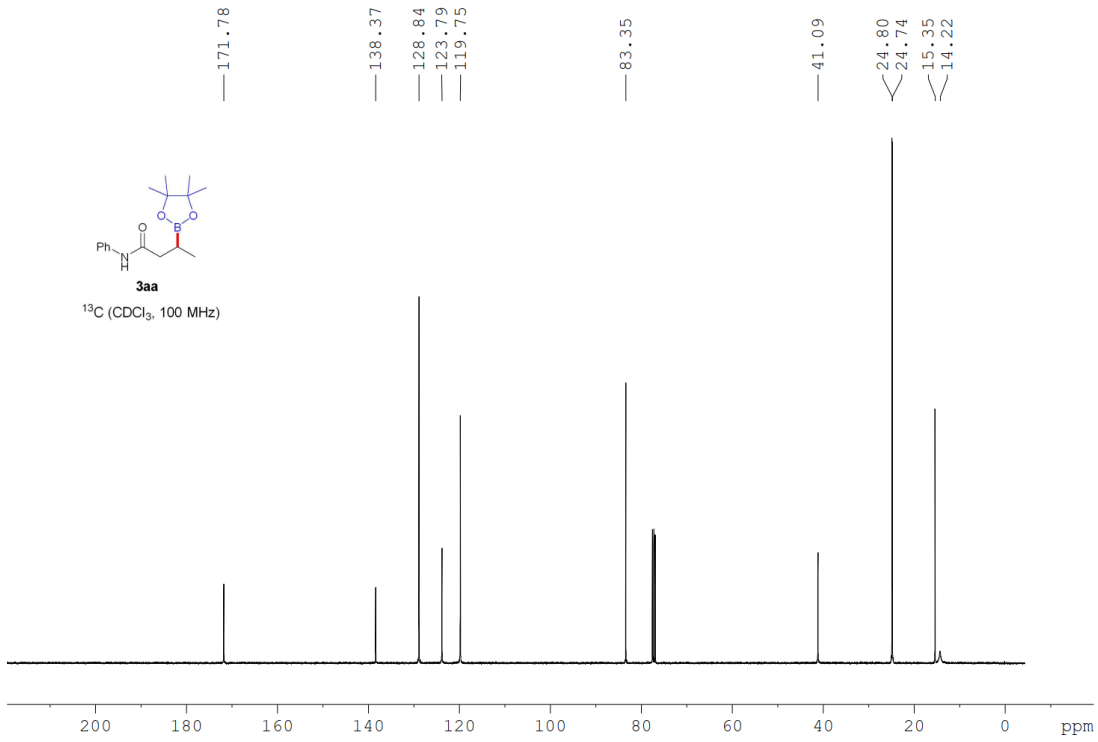
1. Gurak, J. A.; Jr.; Yang, K. S.; Liu, Z.; Engle, K. M. Directed, Regiocontrolled Hydroamination of Unactivated Alkenes via Protodepalladation. *J. Am. Chem. Soc*. **2016**, *138*, 5805-5808.
2. Li, Z.; Wang, Z.; Zhu, L.; Tan, X.; Li, C. Silver-Catalyzed Radical Fluorination of Alkylboronates in Aqueous Solution. *J. Am. Chem. Soc.*, **2014**, *136*, 16439-16443.
3. Hu, J.; Lan, T.; Sun, Y.; Chen, H.; Yao, J.; Rao, Y. Unactivated C(sp^3)-H hydroxylation through palladium catalysis with H_2O as the oxygen source. *Chem. Commun.*, **2015**, *51*, 14929-14932.
4. Sandrock, D. L.; Jean-Gérard, L.; Chen, C.-Y.; Dreher, S. D.; Molander, G. A. Stereospecific Cross-Coupling of Secondary Alkyl β-Trifluoroboratoamides. *J. Am. Chem. Soc.*, **2010**, *132*, 48, 17108-17110.
5. Shi, Y.; Gao, Q.; Xu, S. Chiral Bidentate Boryl Ligand Enabled Iridium-Catalyzed Enantioselective C(sp^3)-H Borylation of Cyclopropanes. *J. Am. Chem. Soc.*, **2019**, *141*, 10599-10604.
6. Gaspar, B.; Carreira, E. M. Catalytic Hydrochlorination of Unactivated Olefins with para-Toluenesulfonyl Chloride. *Angew. Chem. Int. Ed.*, **2008**, *47*, 5758-5760.
7. Molander, G. A.; Wisniewski, S. R.; Hosseini-Sarvari, M. Synthesis and Suzuki-Miyaura Cross-Coupling of Enantioenriched Secondary Potassium β-Trifluoroboratoamides: Catalytic, Asymmetric Conjugate Addition of Bisboronic Acid and Tetrakis(dimethylamino)diboron to α,β-Unsaturated Carbonyl Compounds. *Adv. Synth. Catal.,* **2013**, *355*, 3037-305.
8. Jankins, T. C.; Martin-Montero, R.; Cooper, P.; Martin, Ruben.; Engle, K. M. Low-Valent Tungsten Catalysis Enables Site-Selective Isomerization-Hydroboration of Unactivated Alkenes. *J. Am. Chem. Soc.*, **2021**, *143*, 14981-14986

7. Copies of NMR Spectra

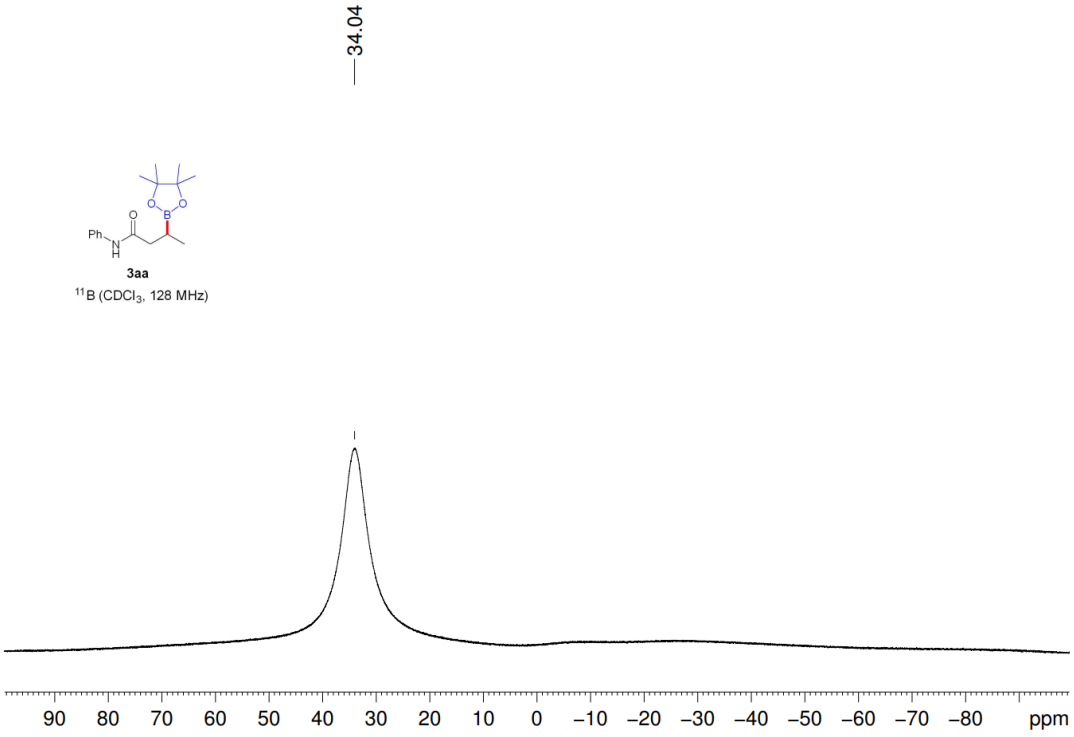
^{1}H NMR Spectra of **3aa**



^{13}C NMR Spectra of **3aa**



^{11}B NMR Spectra of **3aa**



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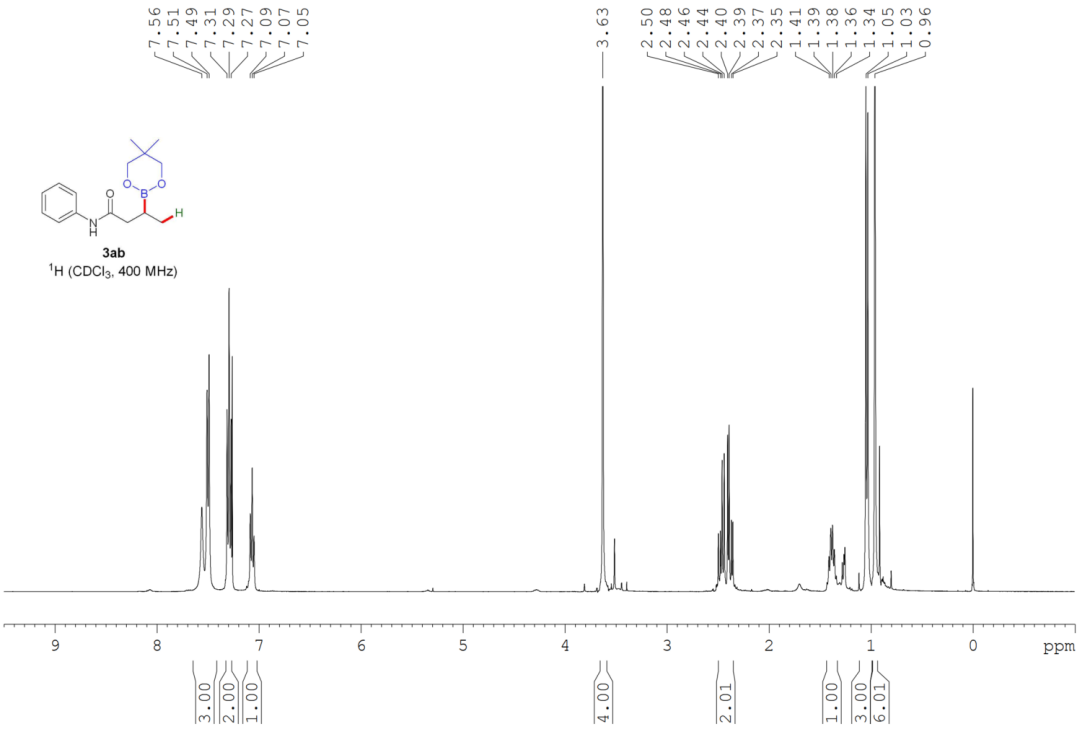
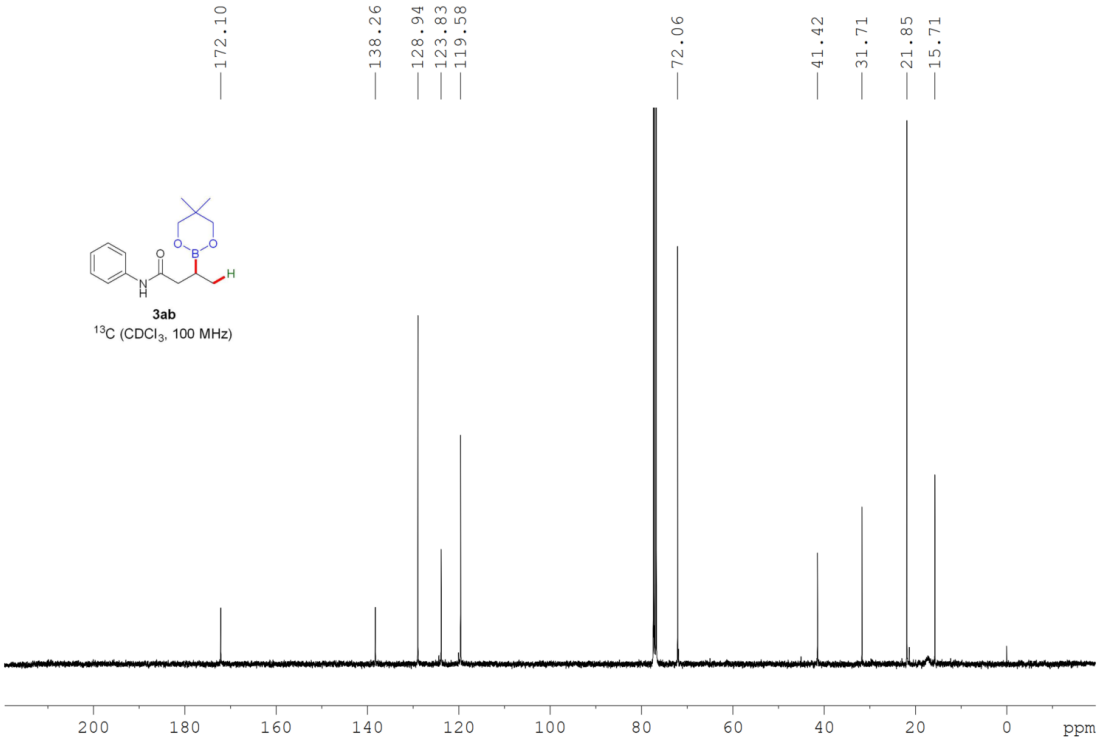


^{13}C NMR Spectra of **3ab**



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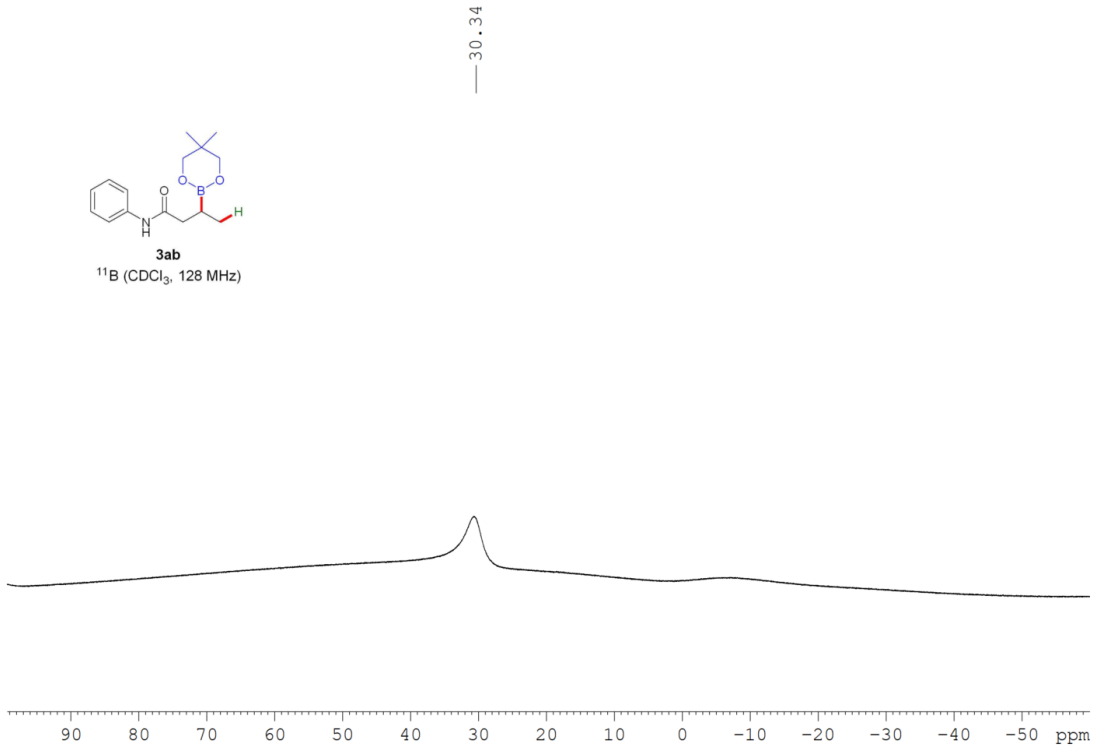

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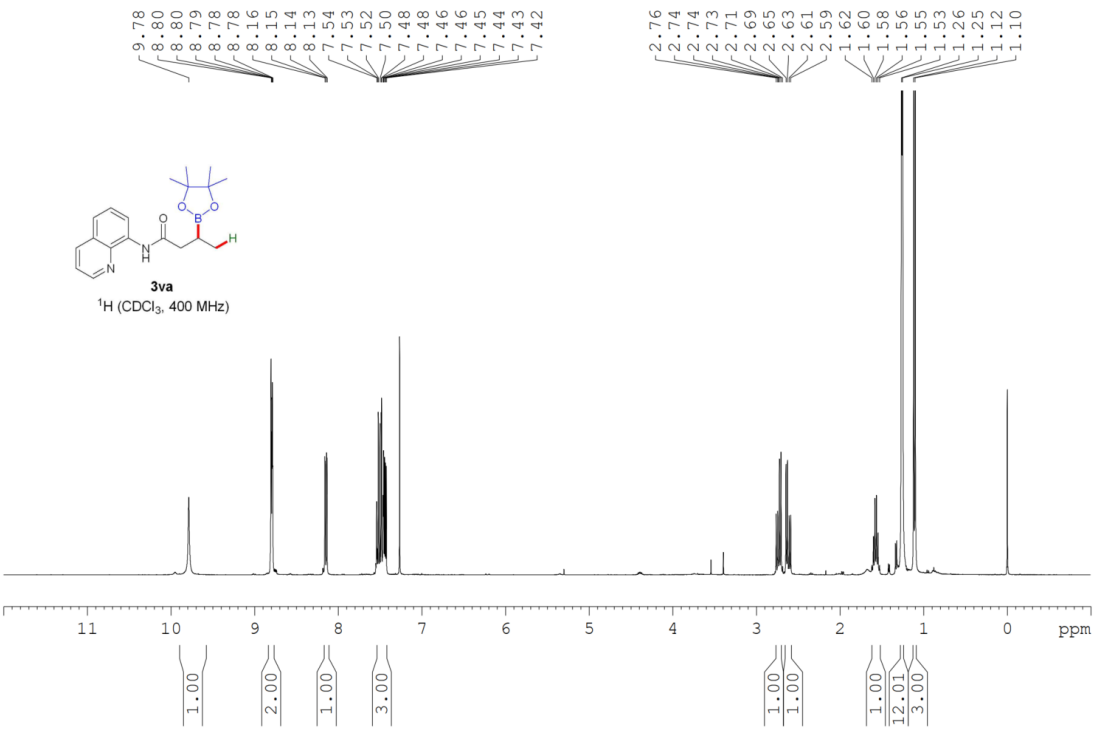

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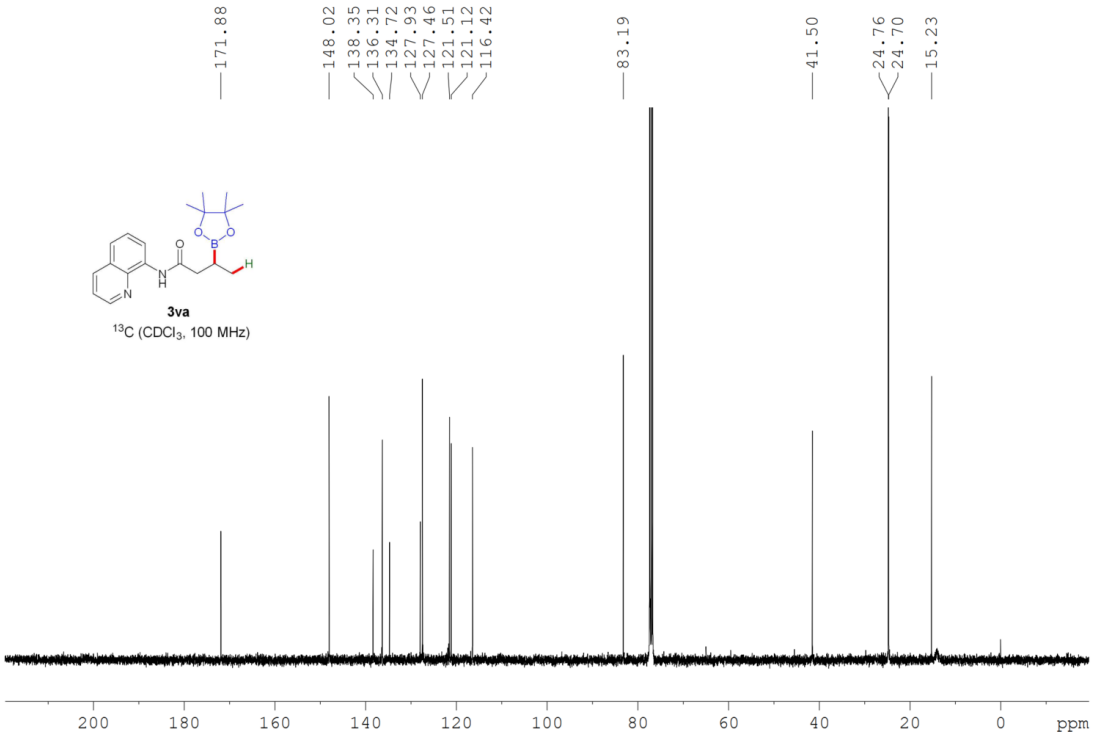

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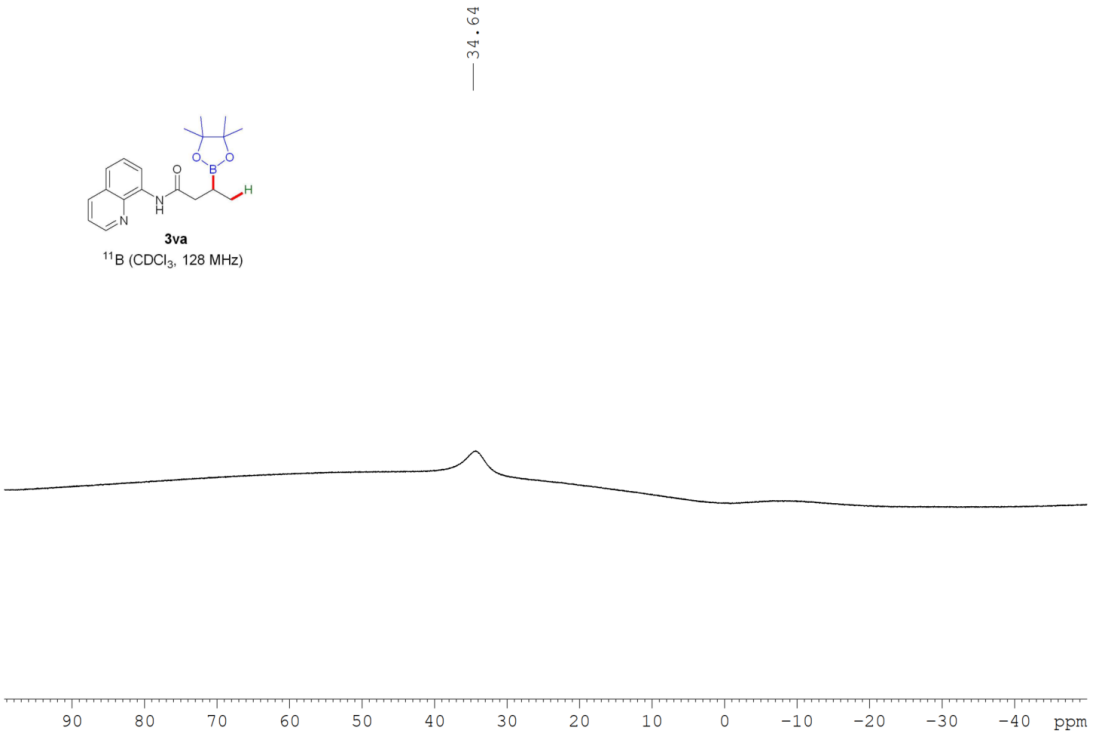
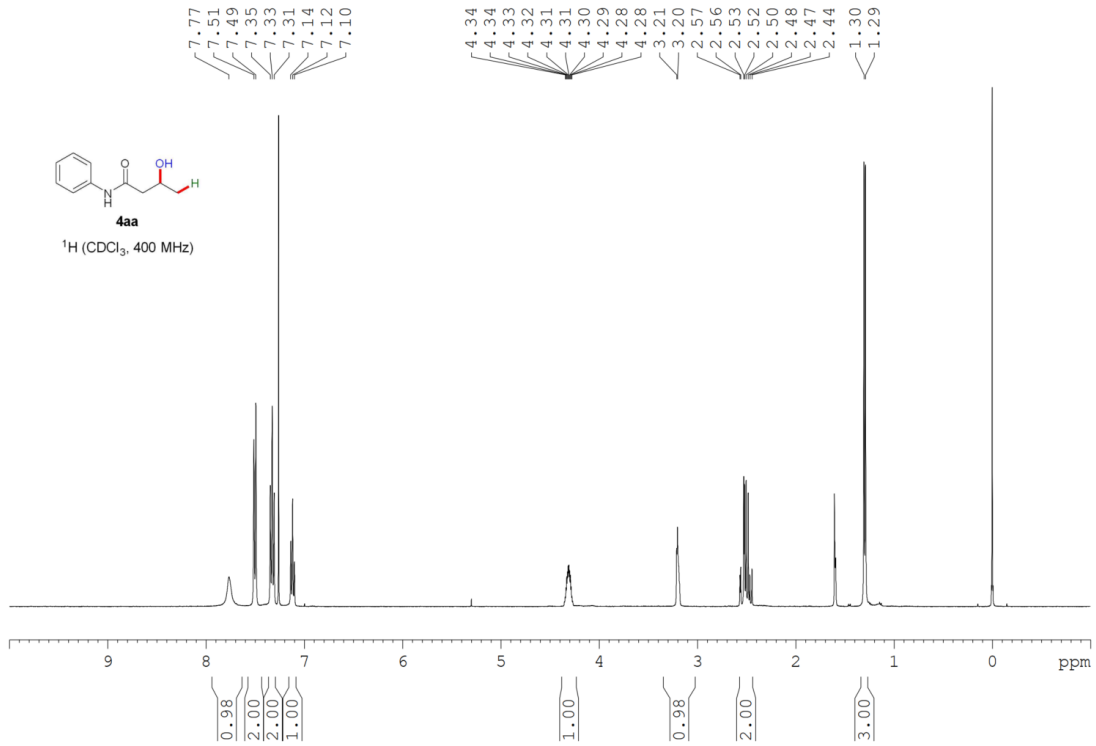


^{1}H NMR Spectra of **4aa**



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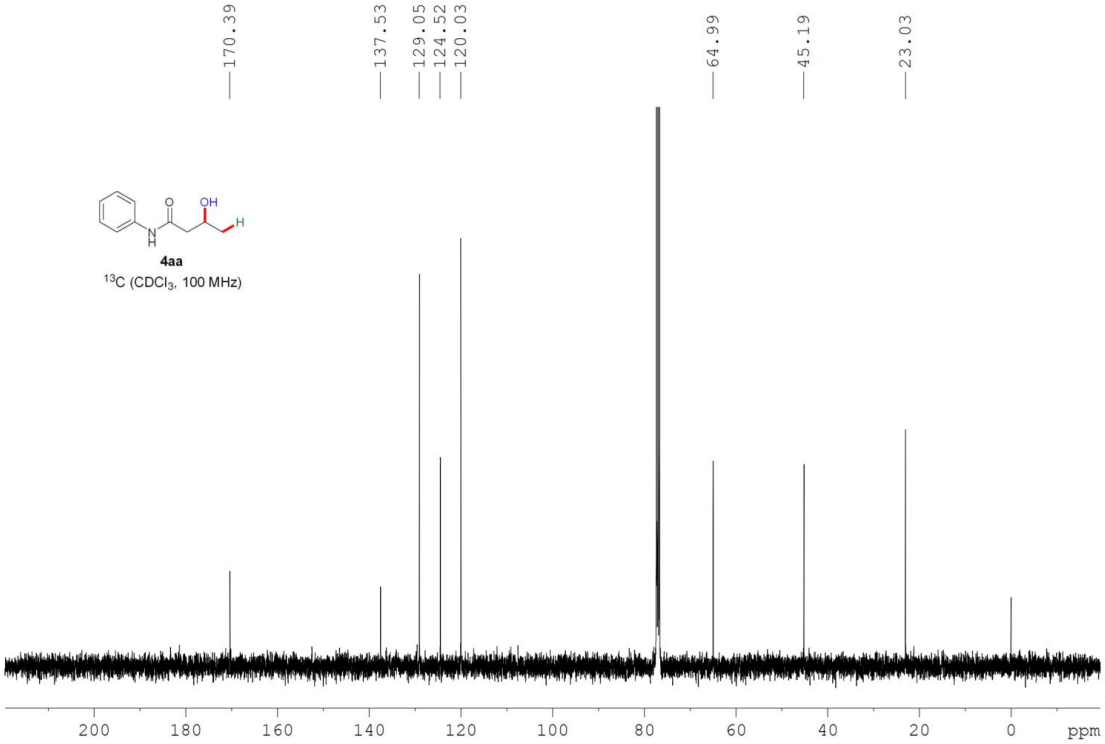

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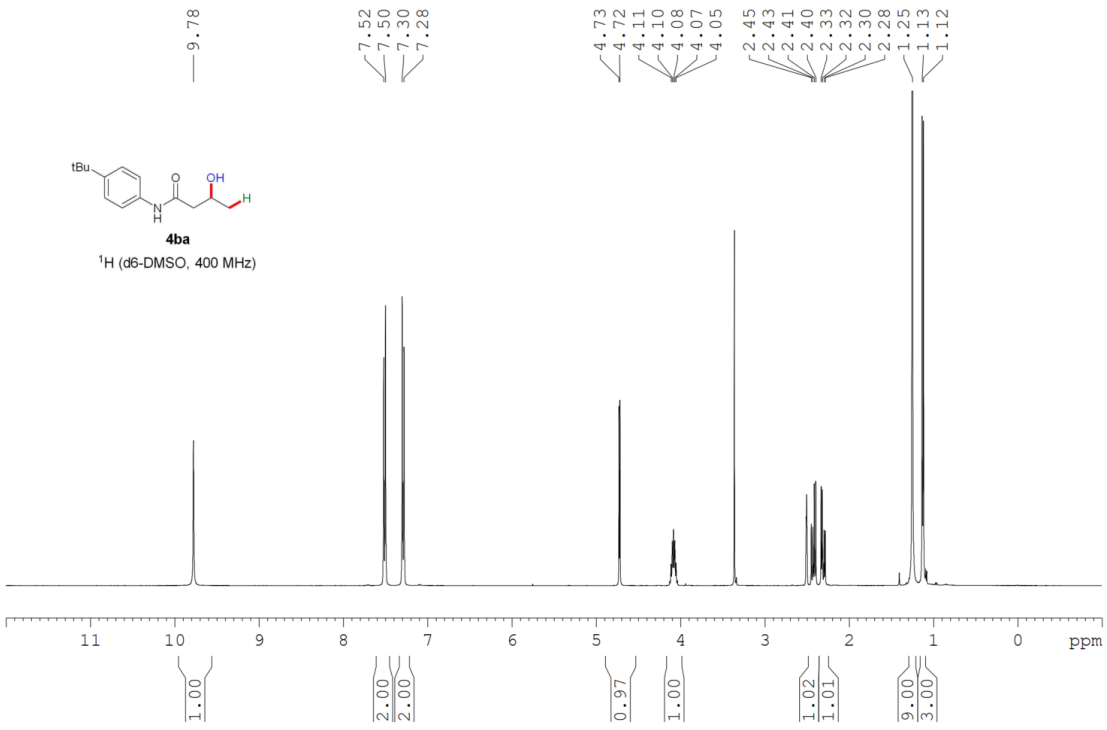

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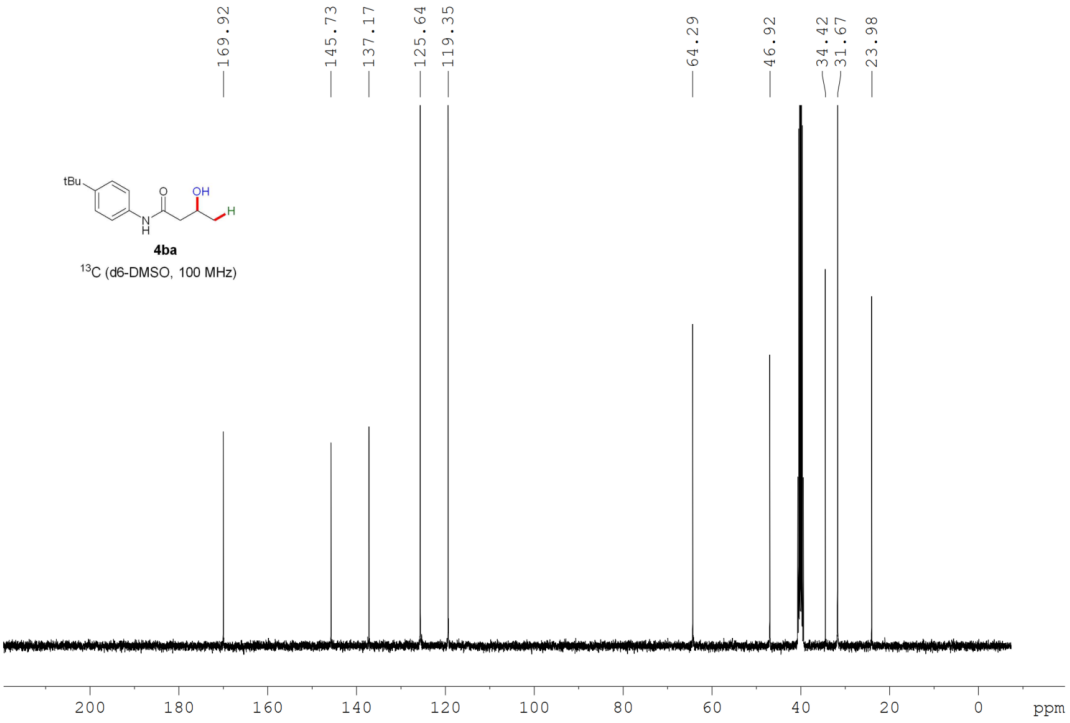

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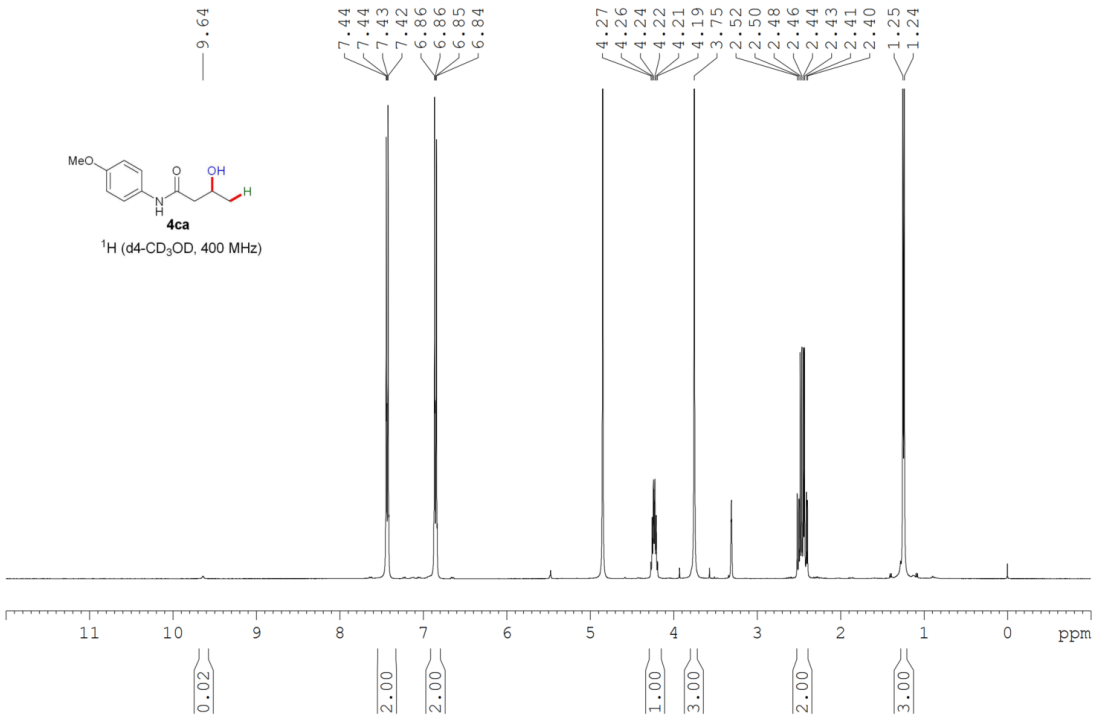

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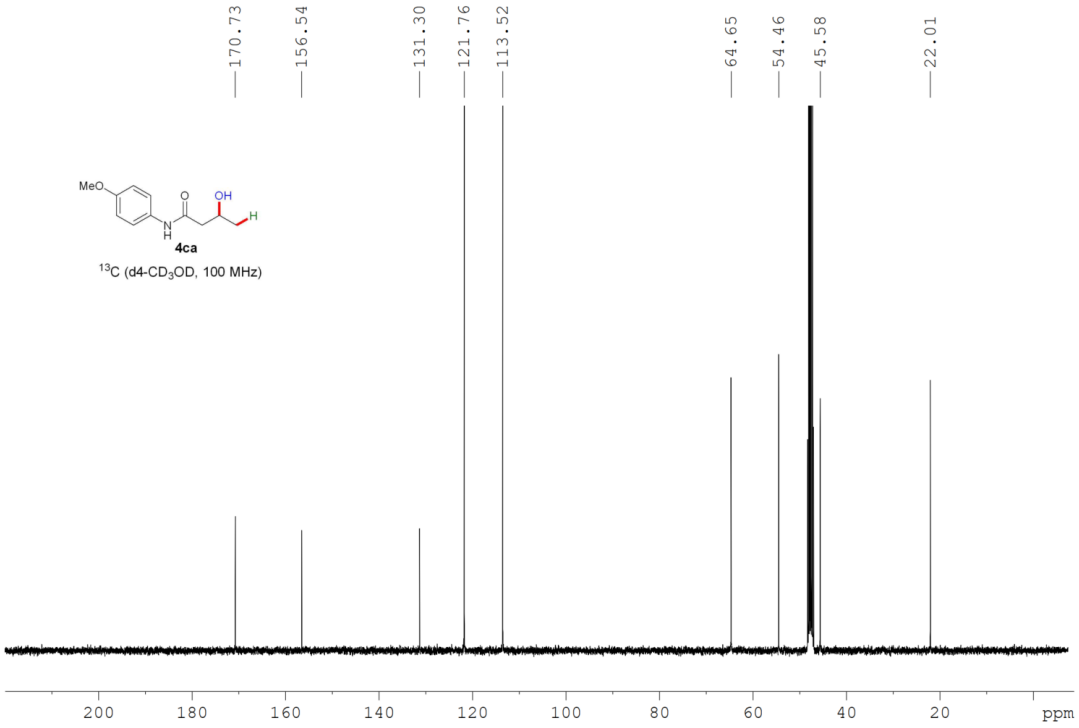

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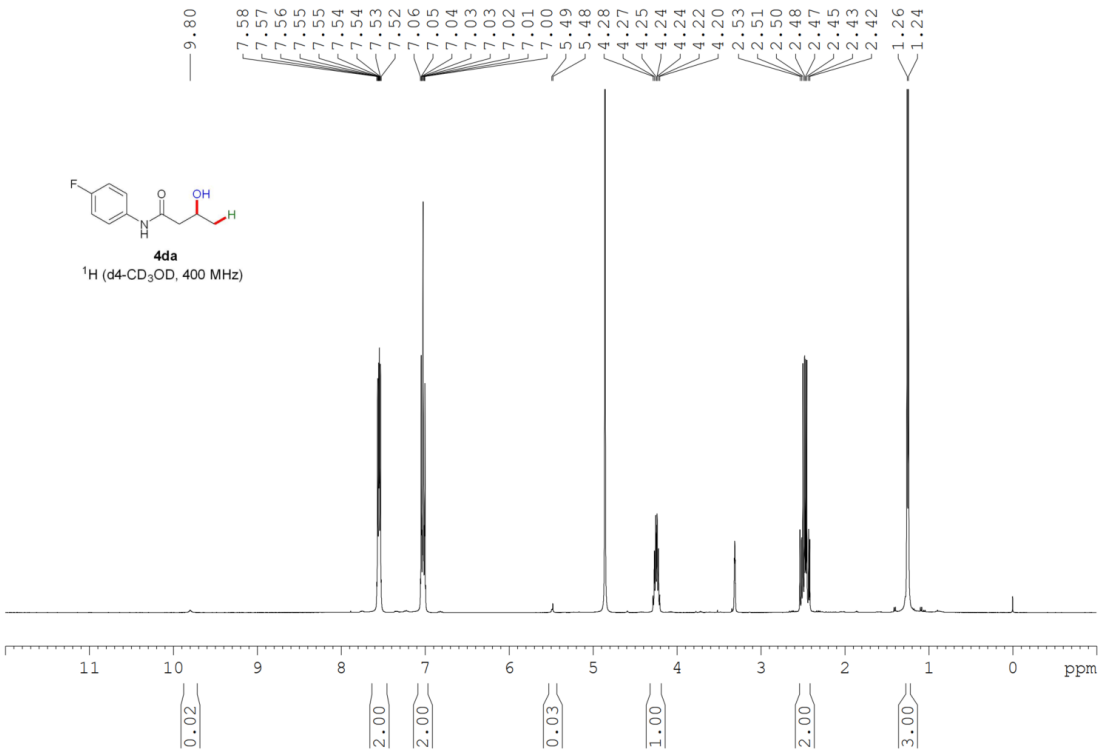

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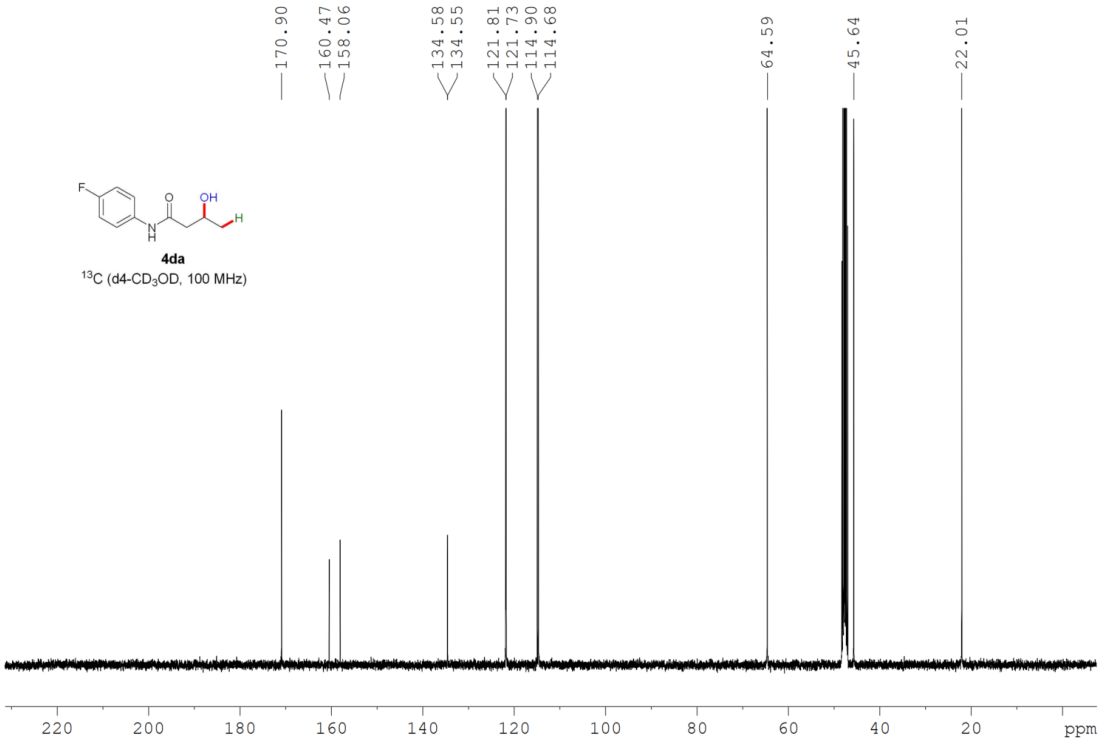
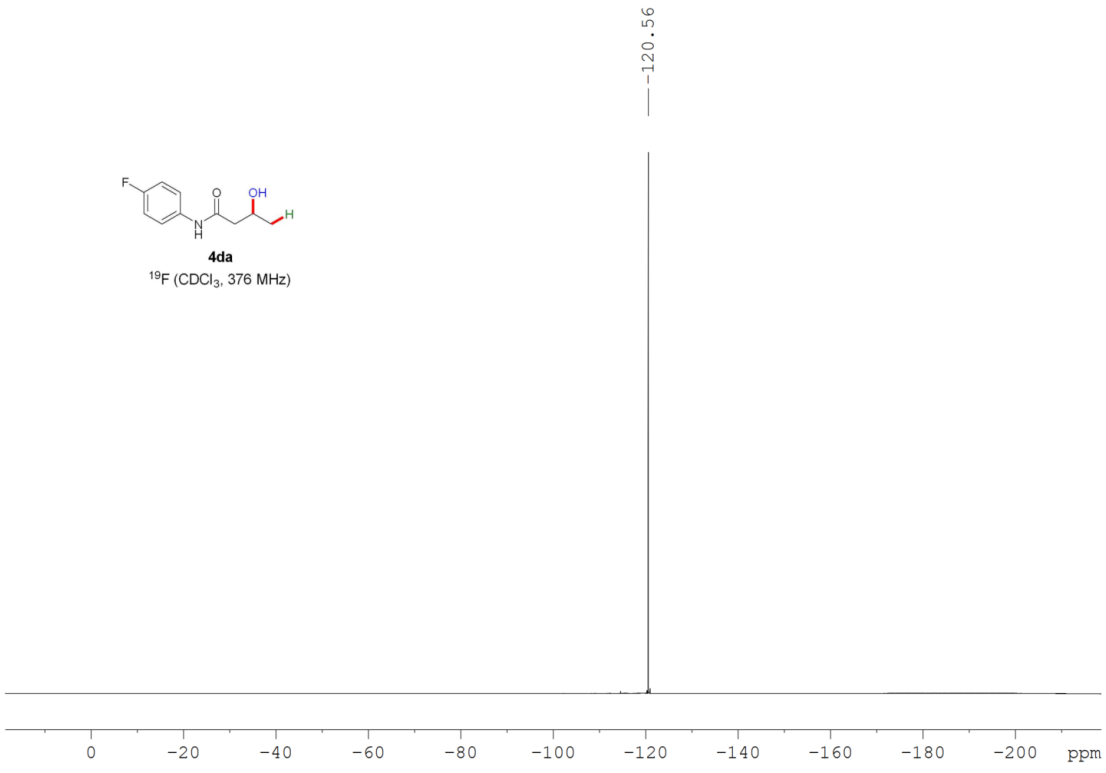


^{19}F NMR Spectra of **4da**



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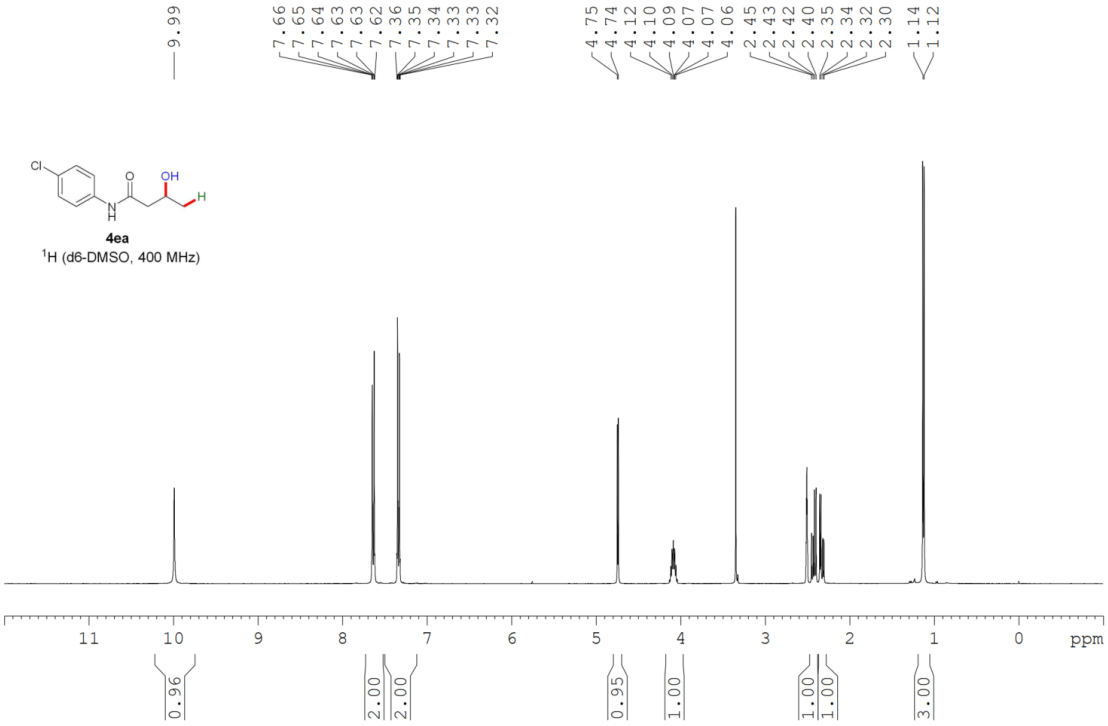

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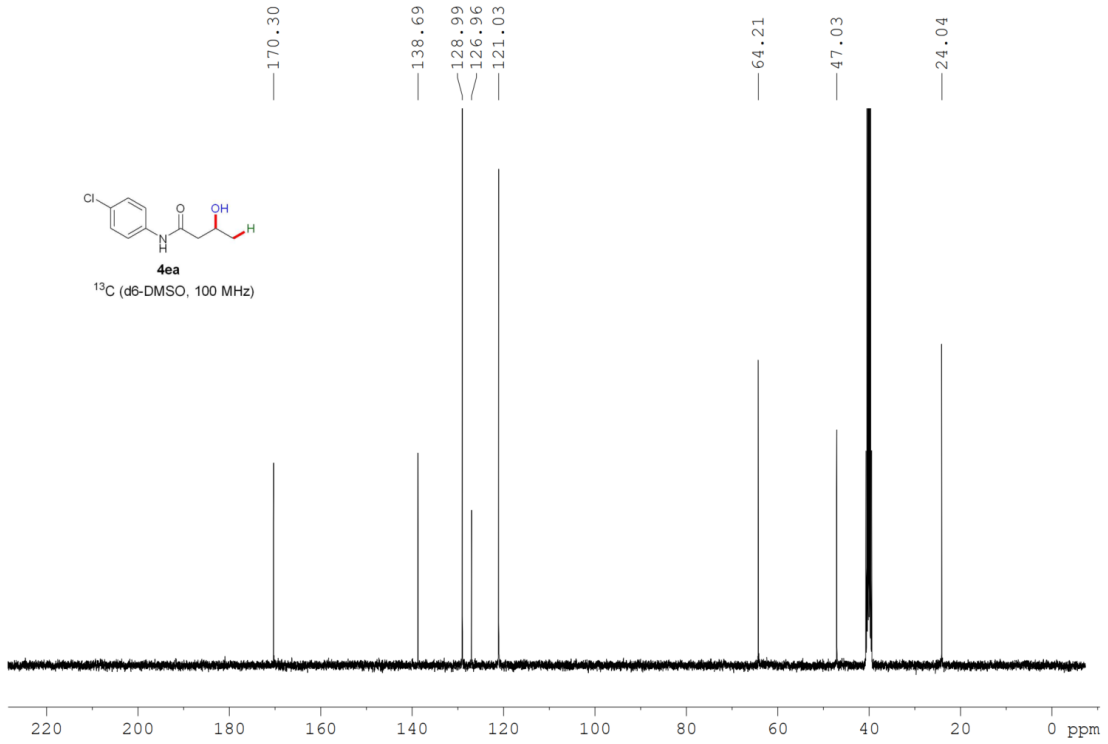

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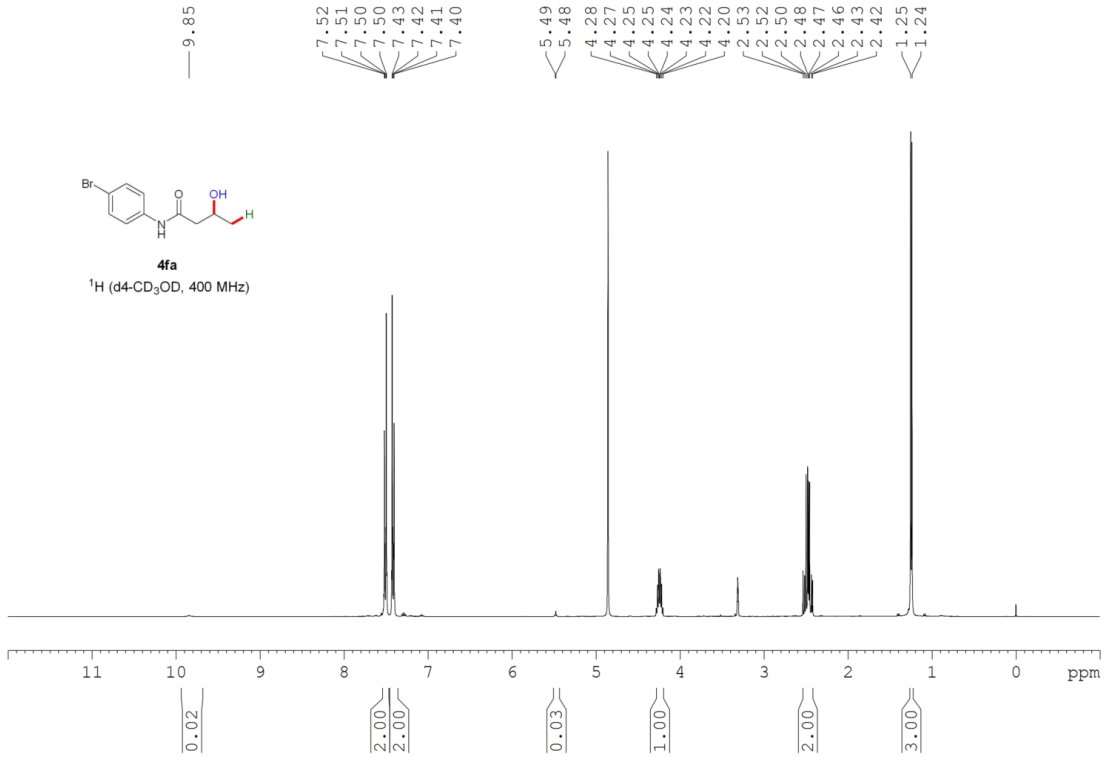

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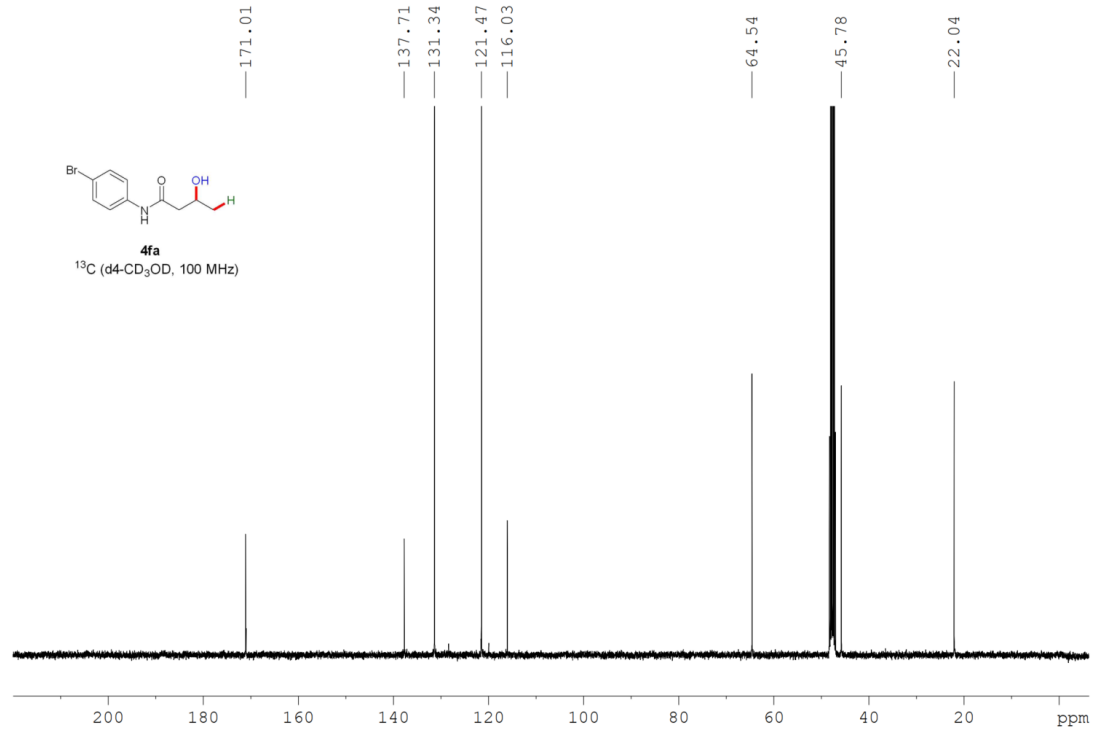

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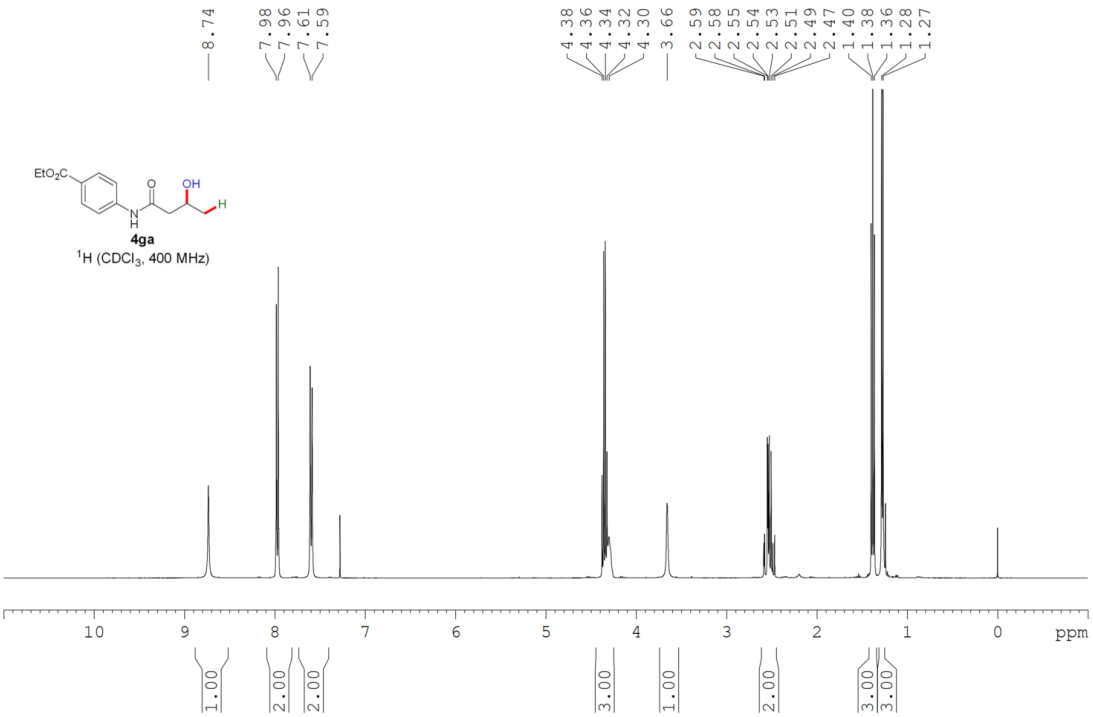

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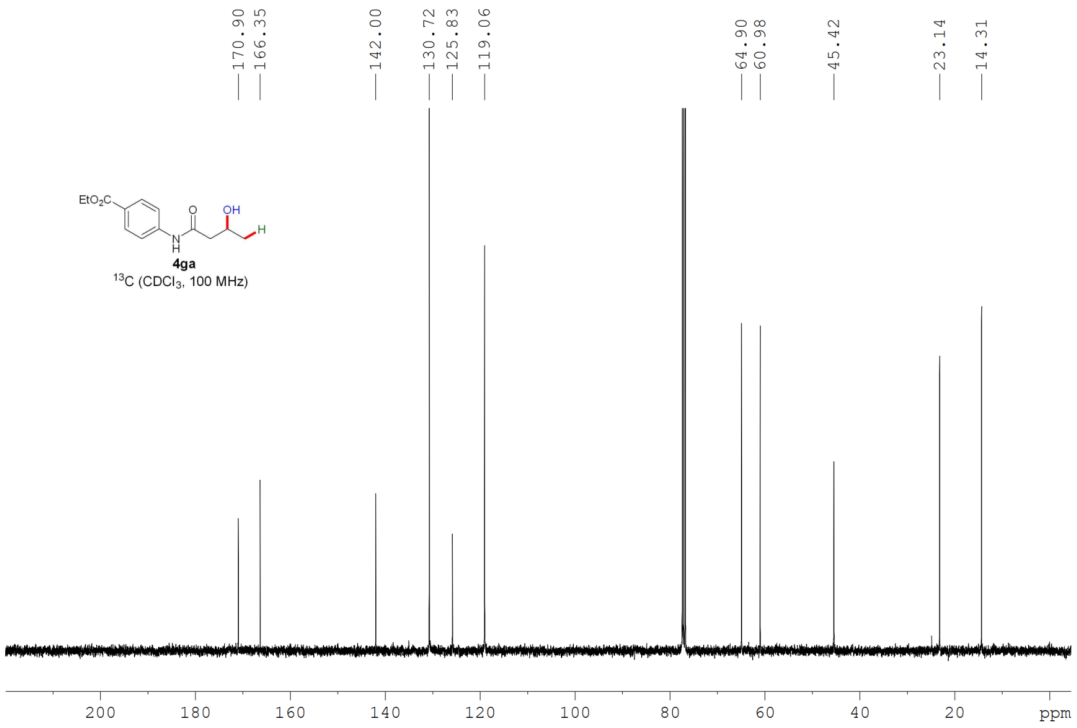

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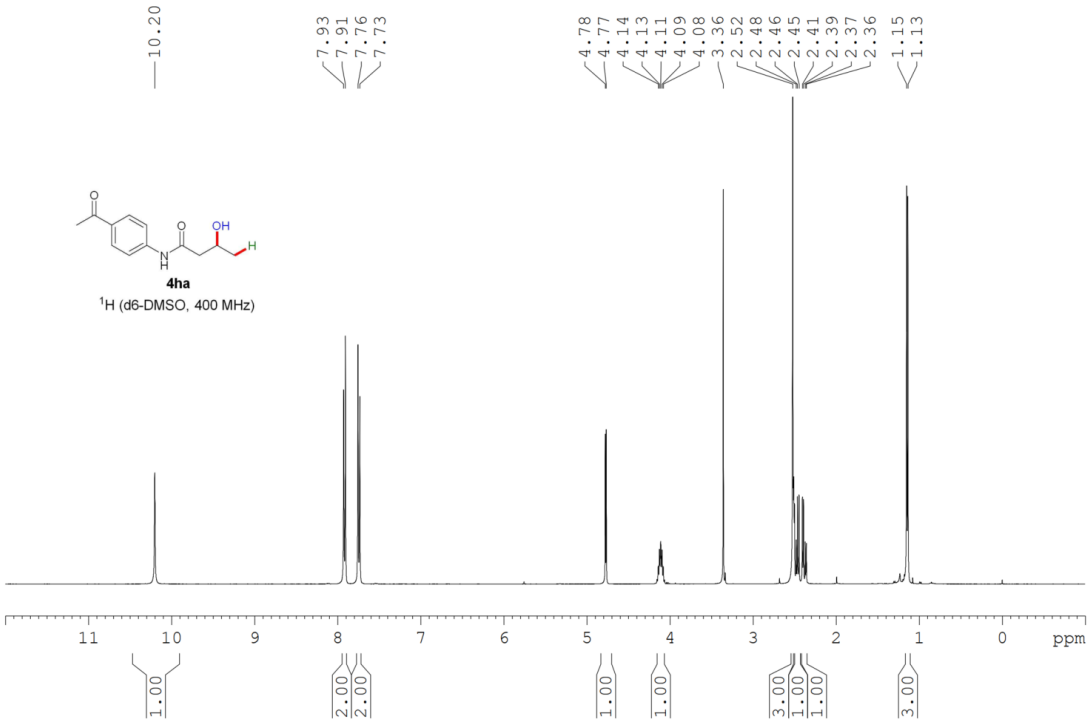

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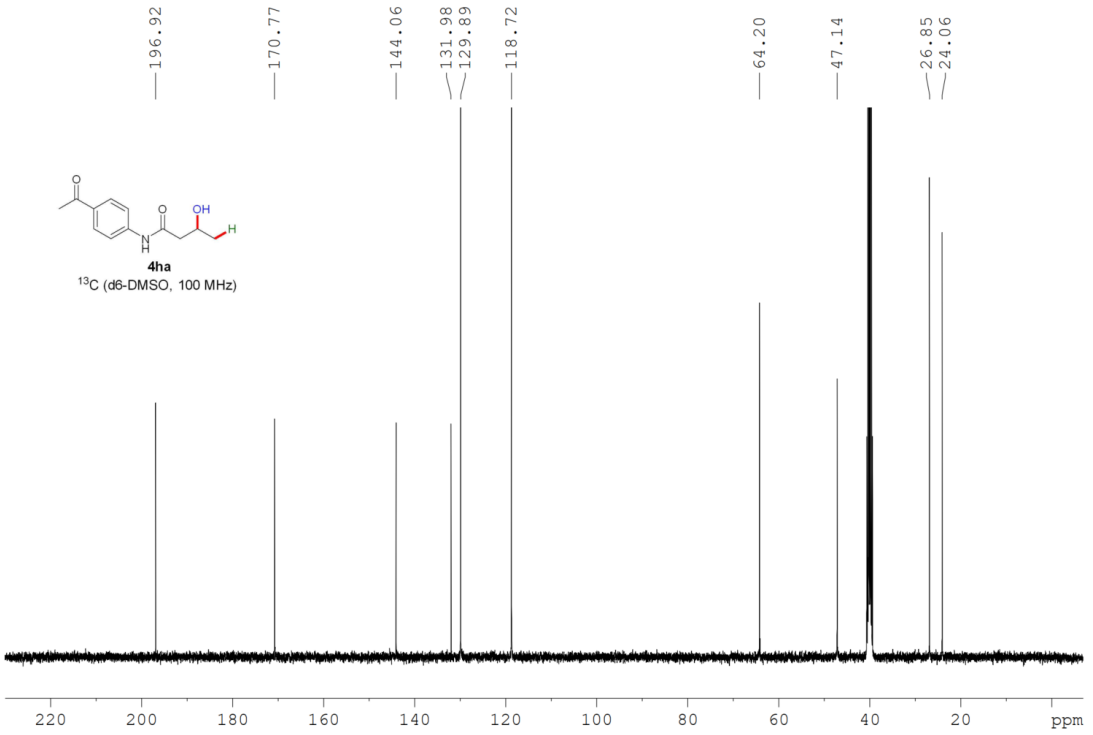
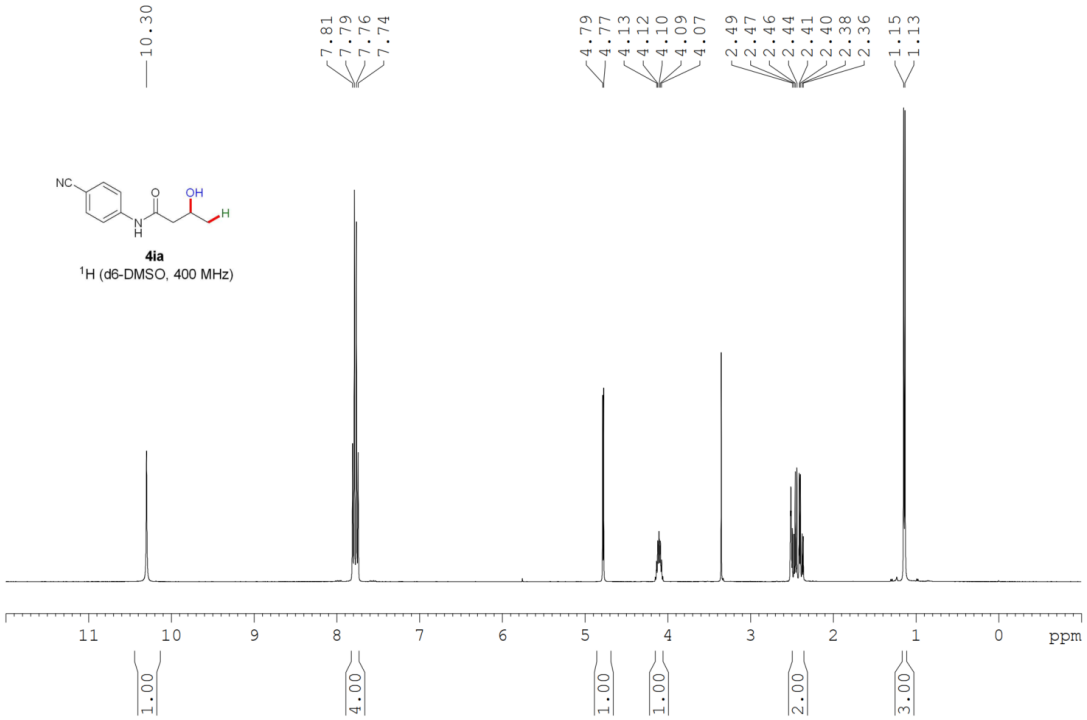


^{1}H NMR Spectra of **4ia**



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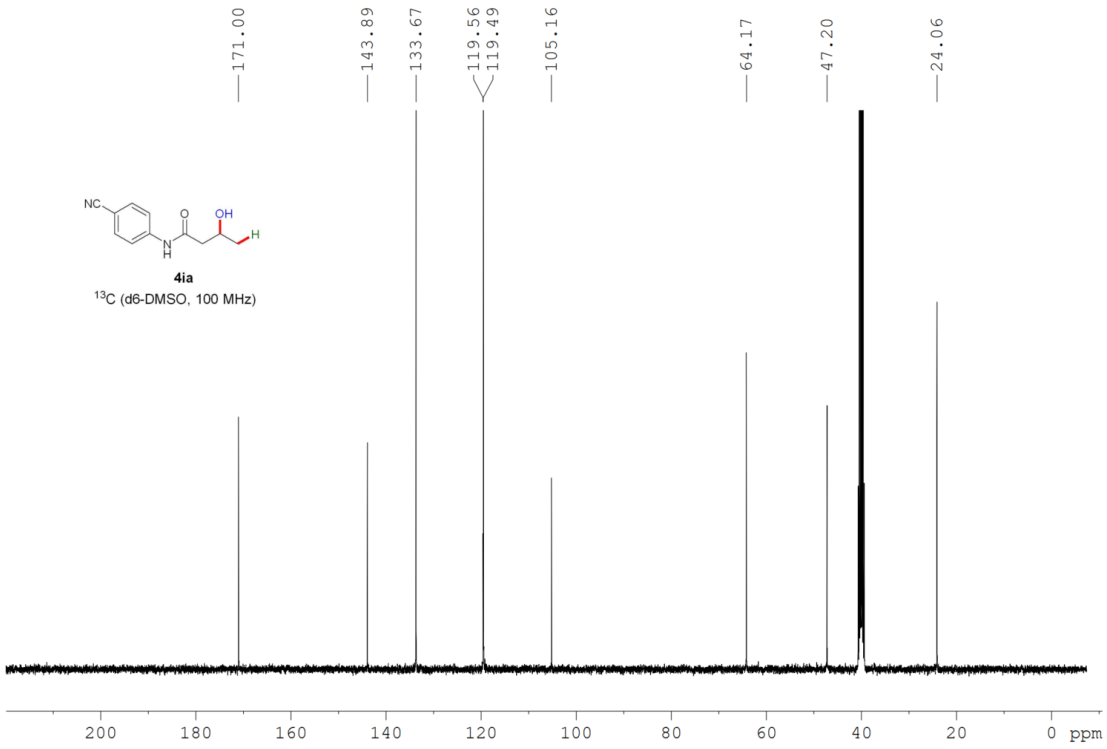

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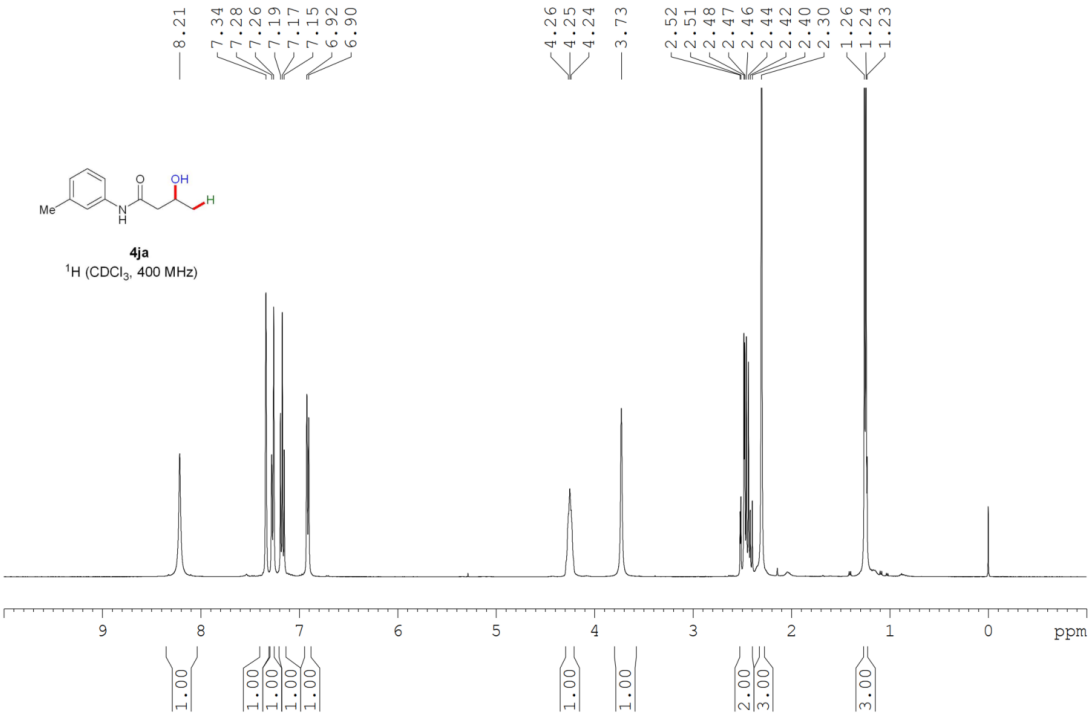

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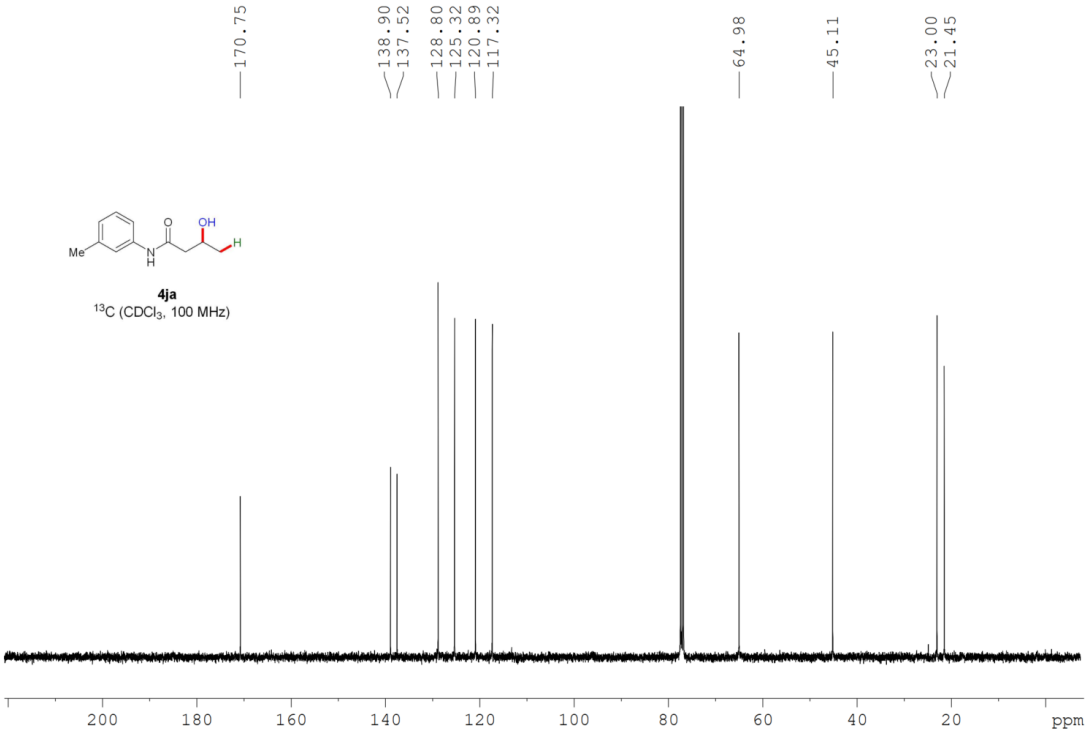

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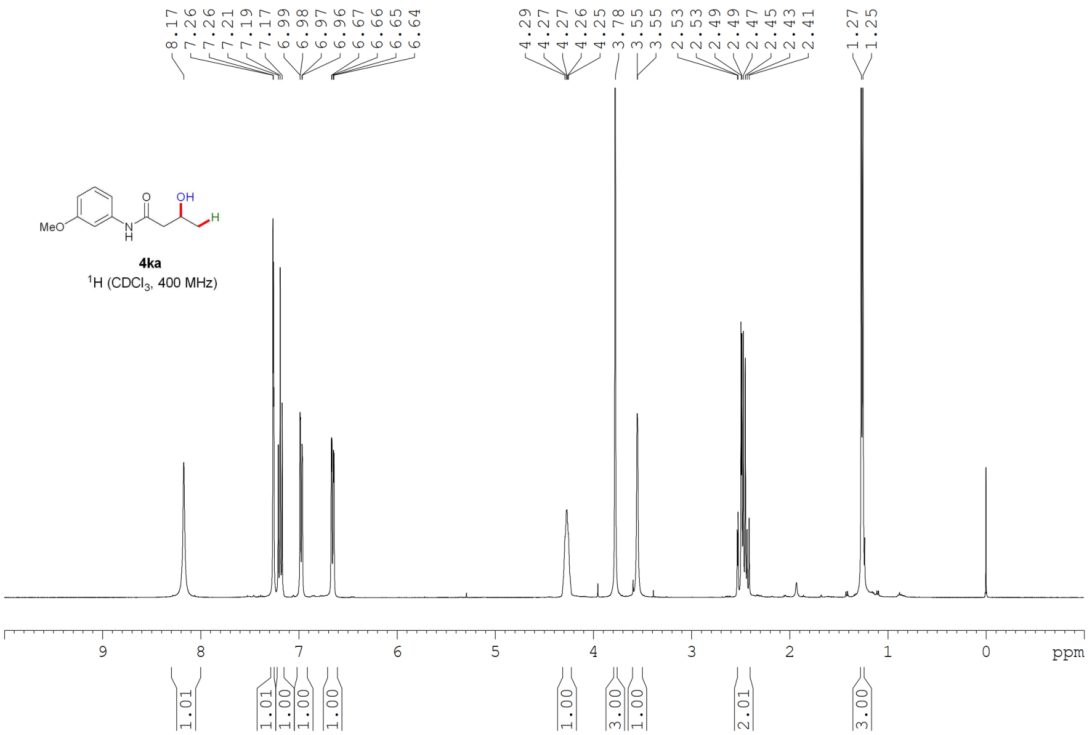

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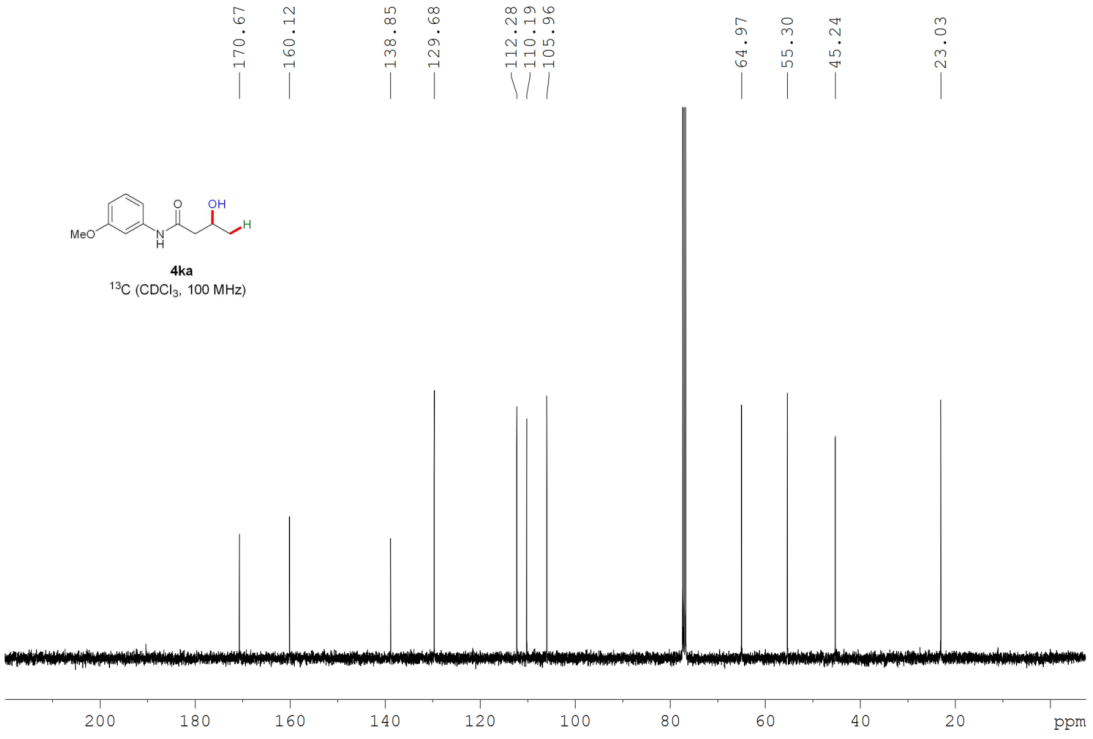

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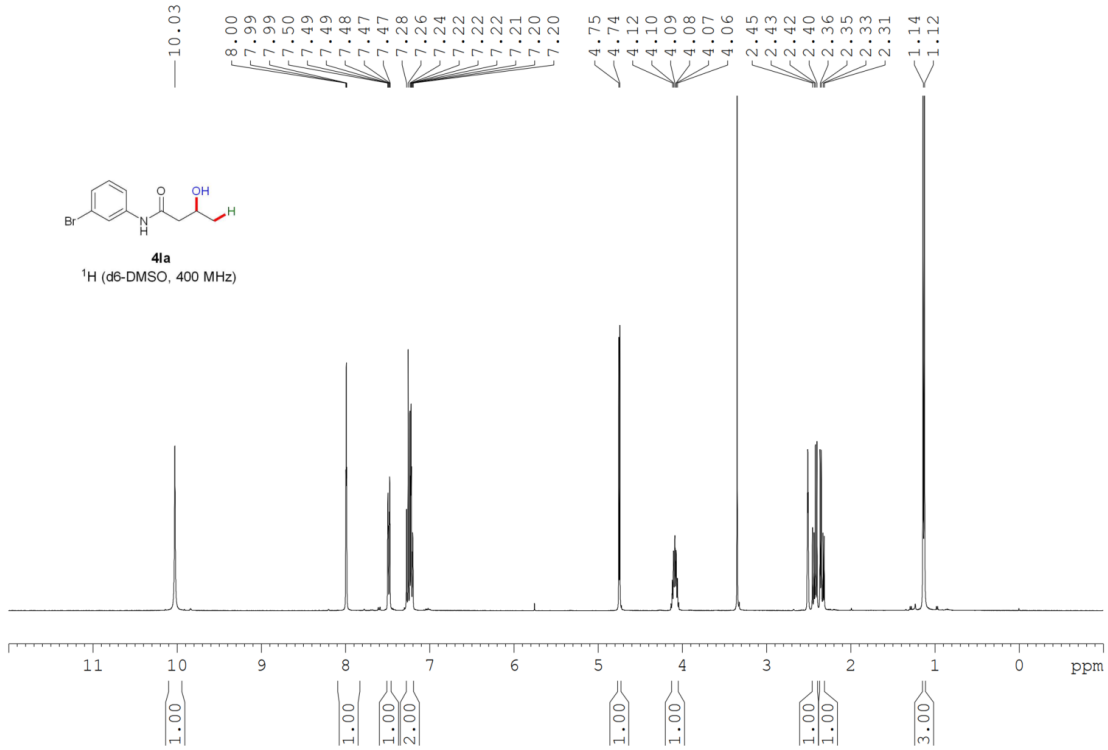

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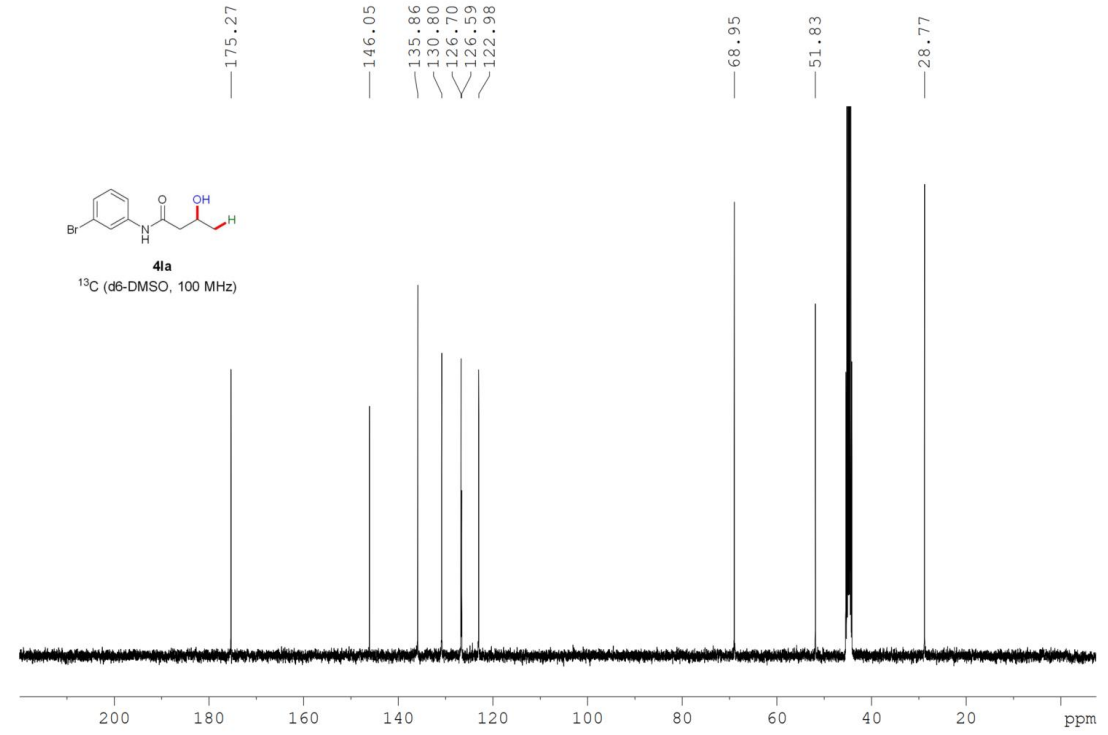

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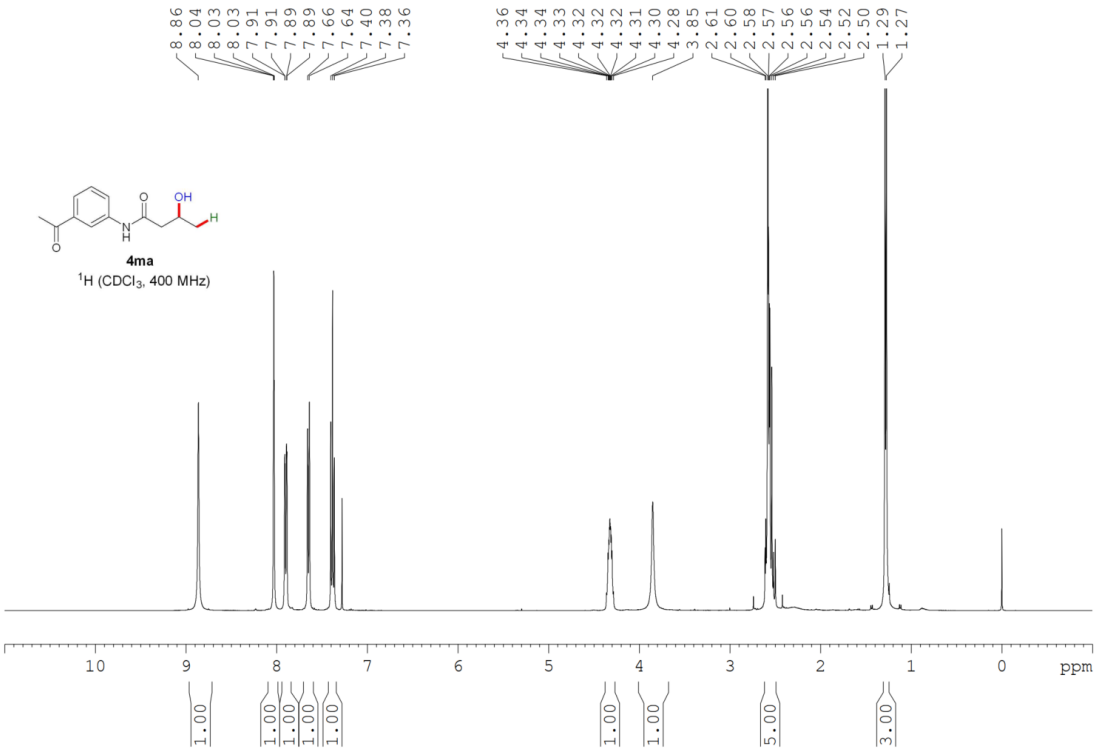

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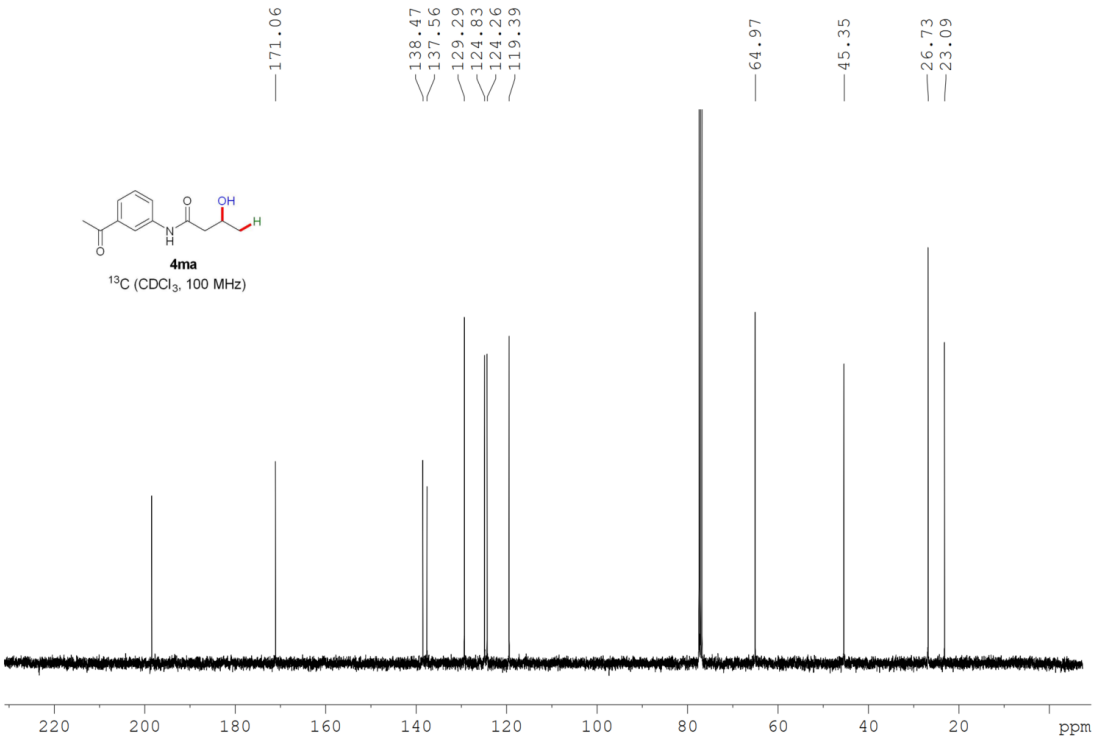

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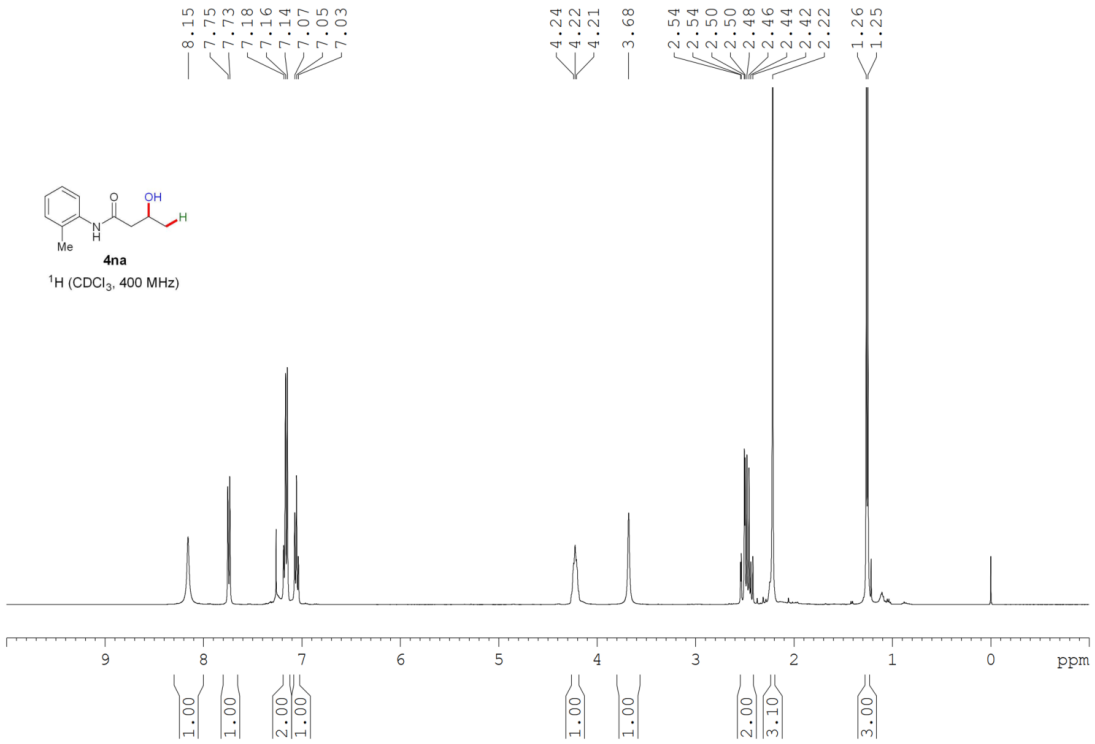

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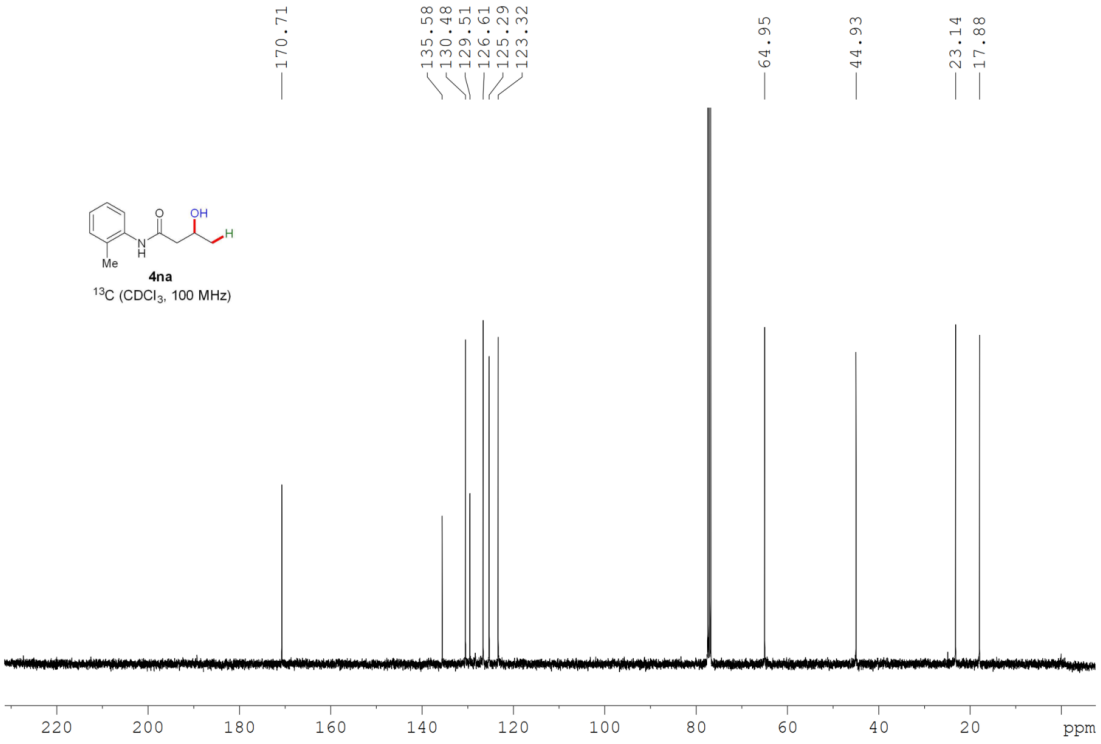

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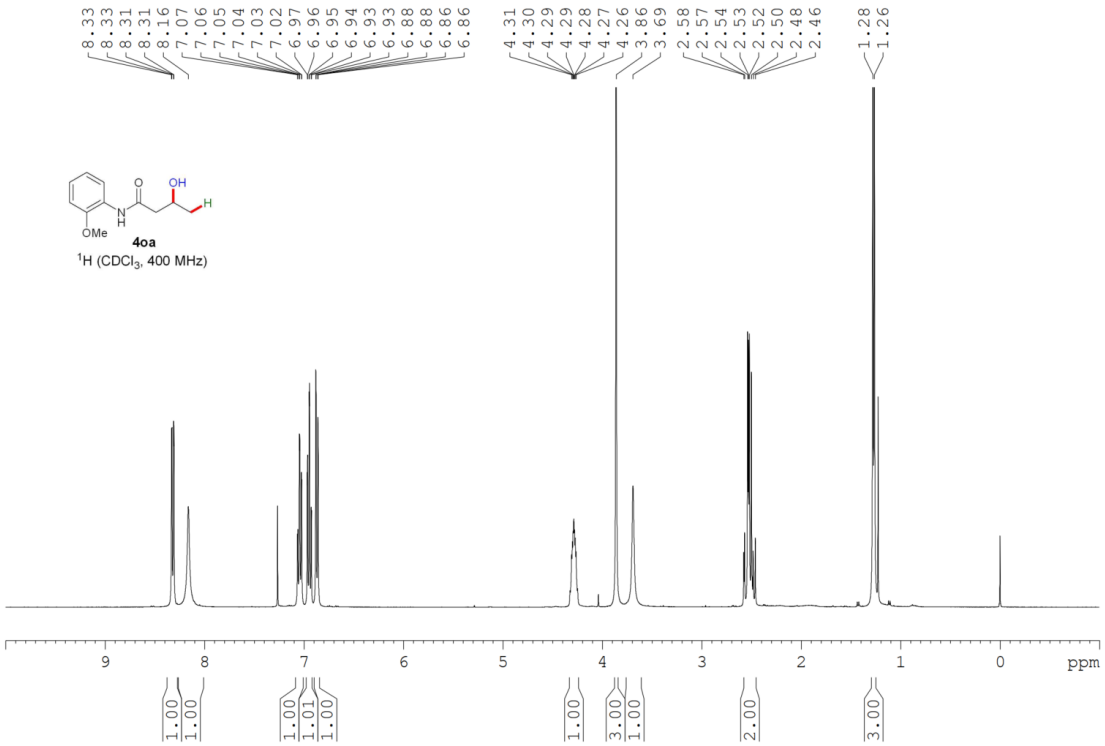

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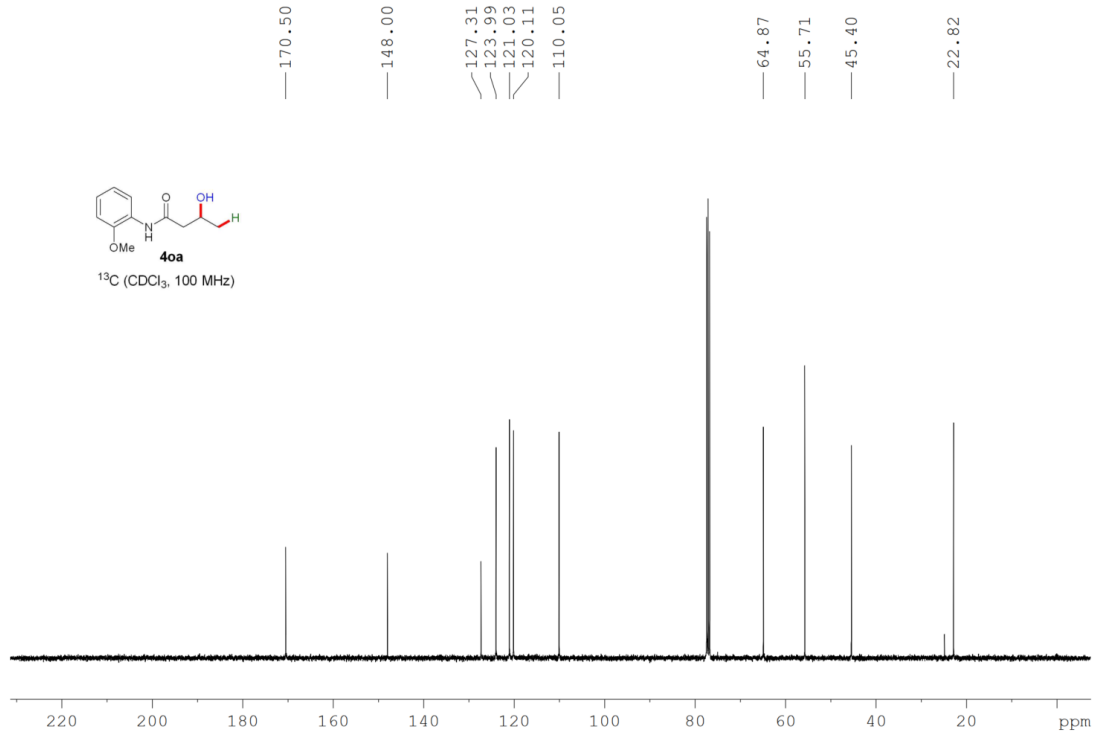

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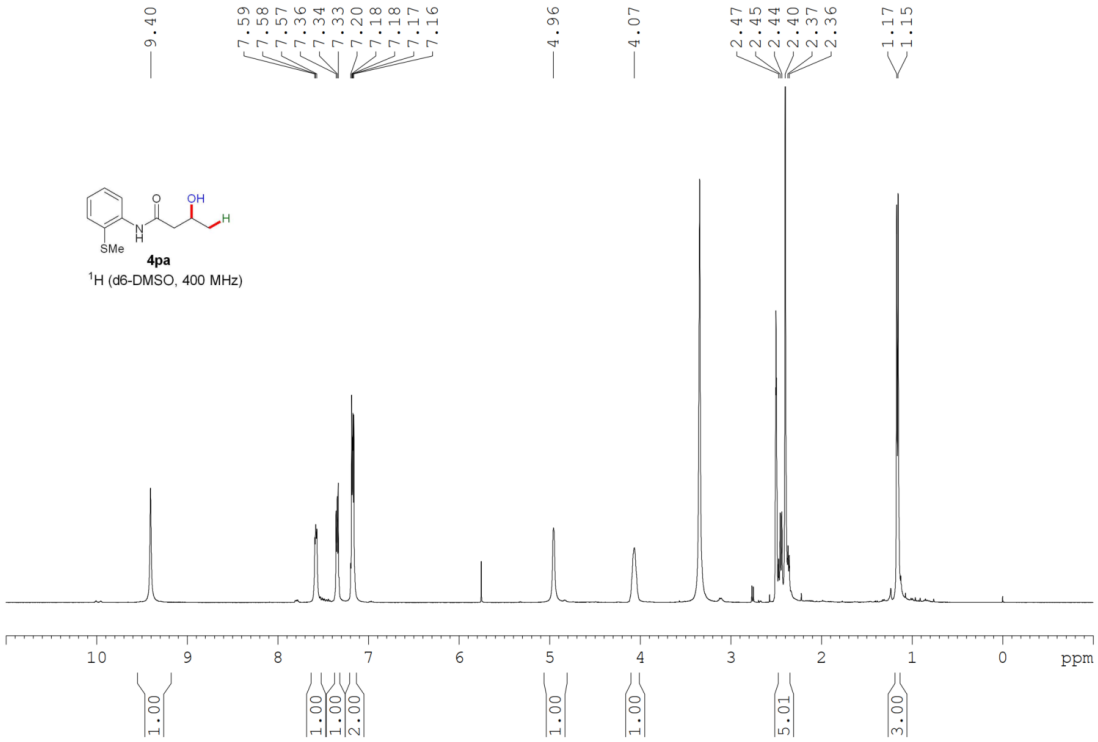
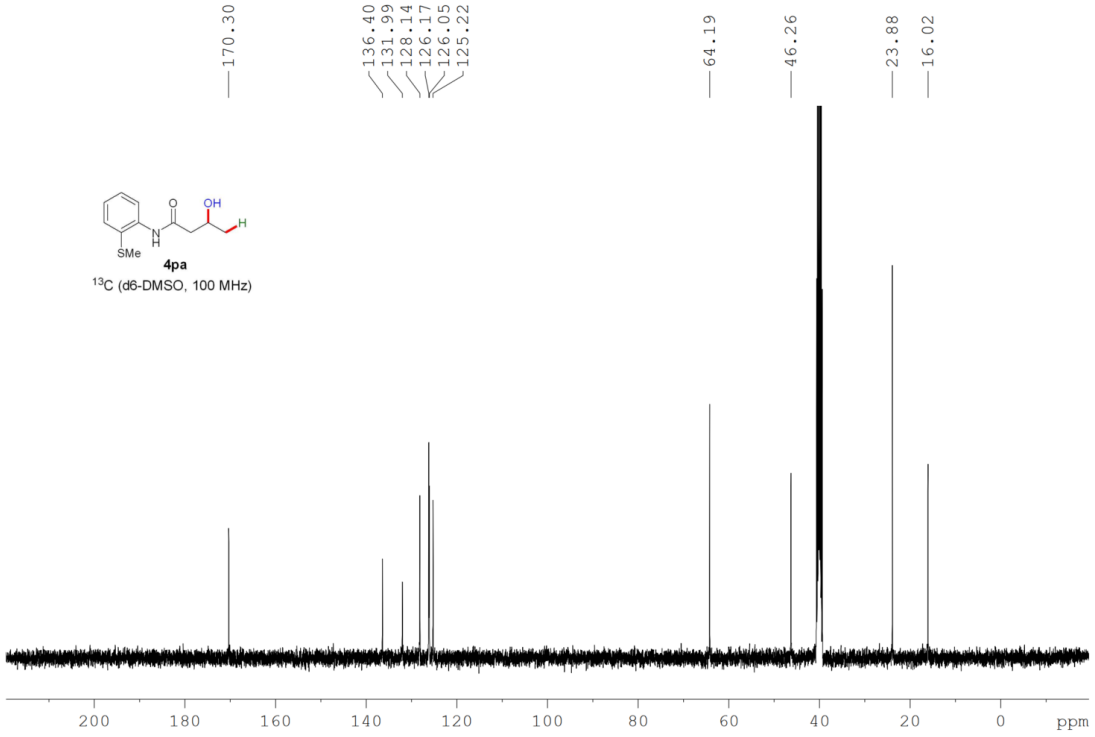
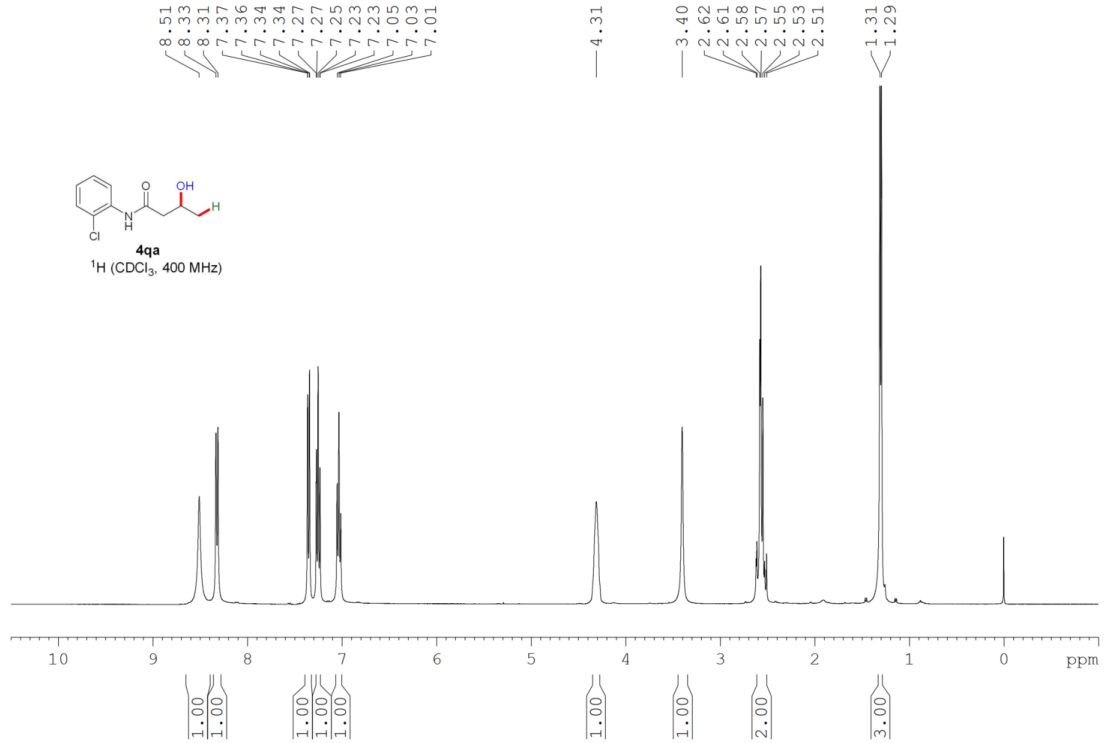


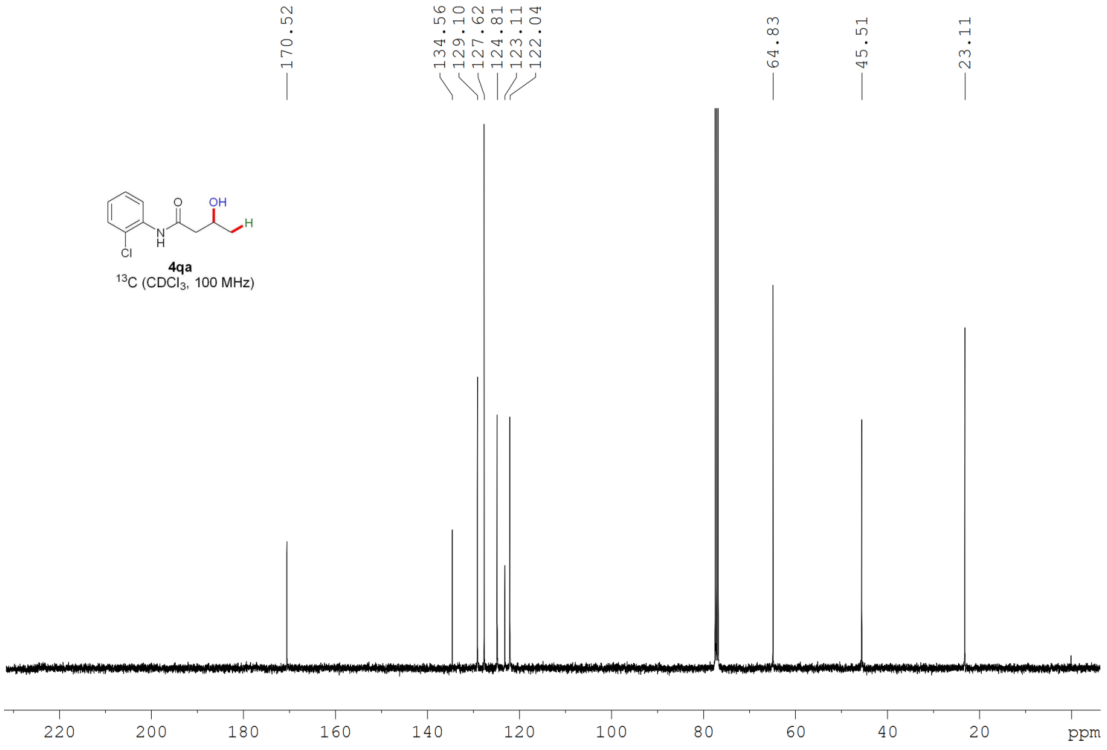
^{13}C NMR Spectra of **4pa**



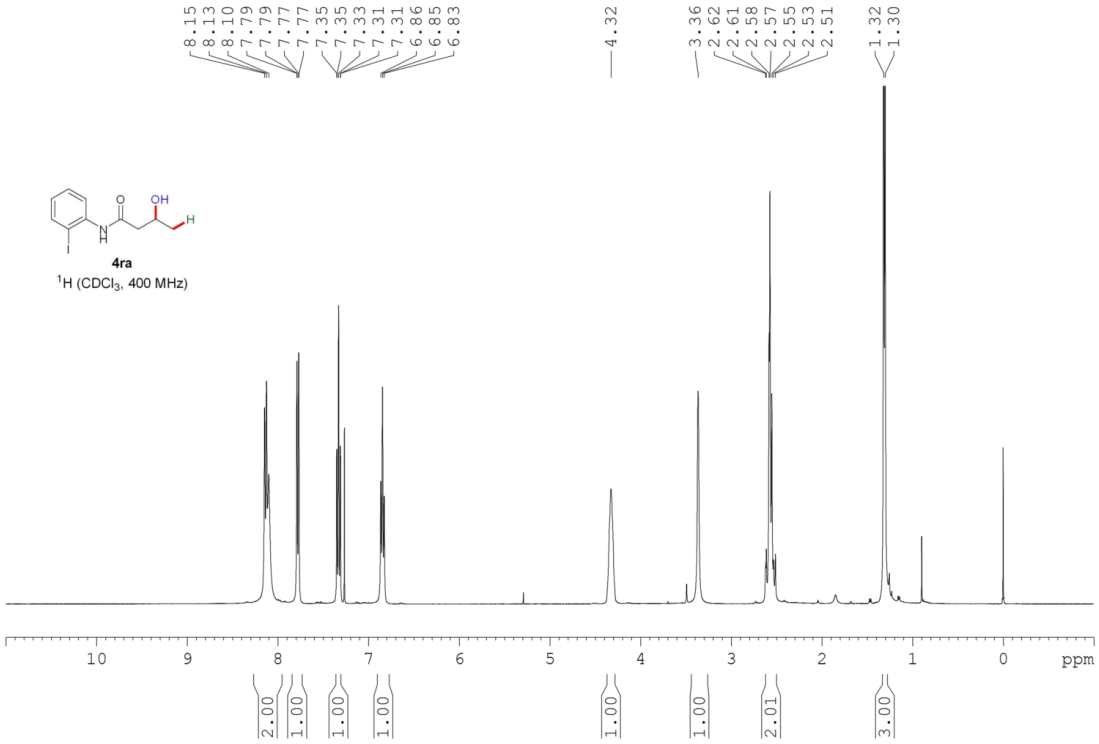
^{1}H NMR Spectra of **4qa**



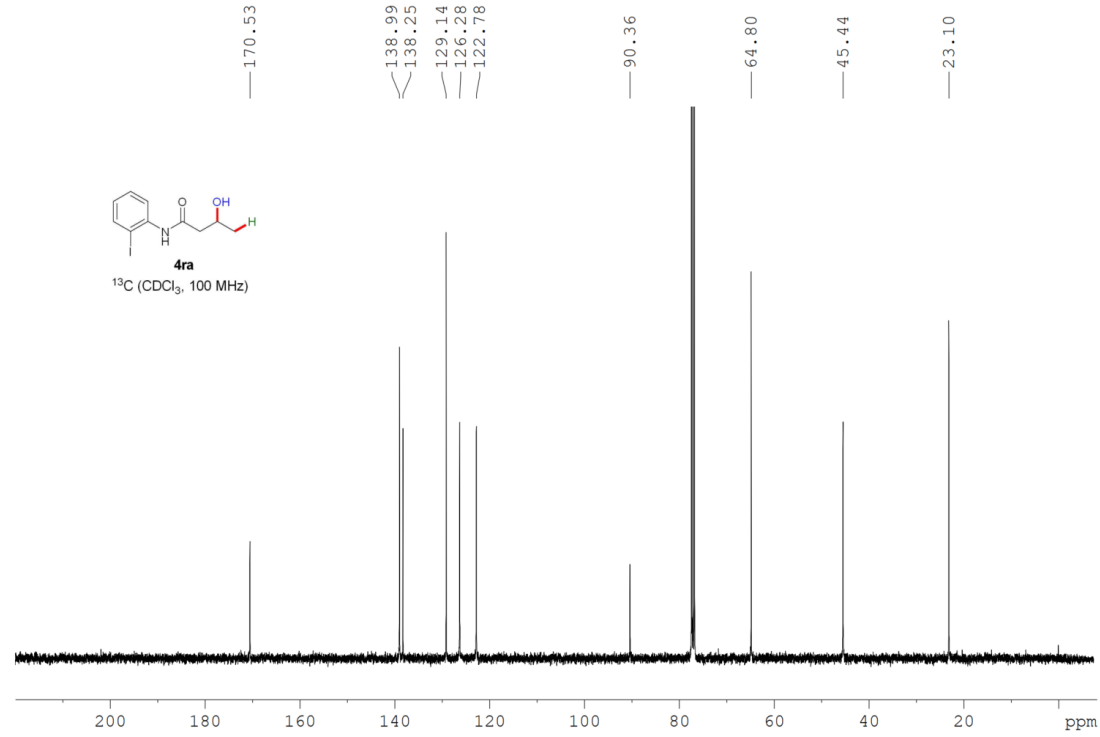
^{13}C NMR Spectra of **4qa**



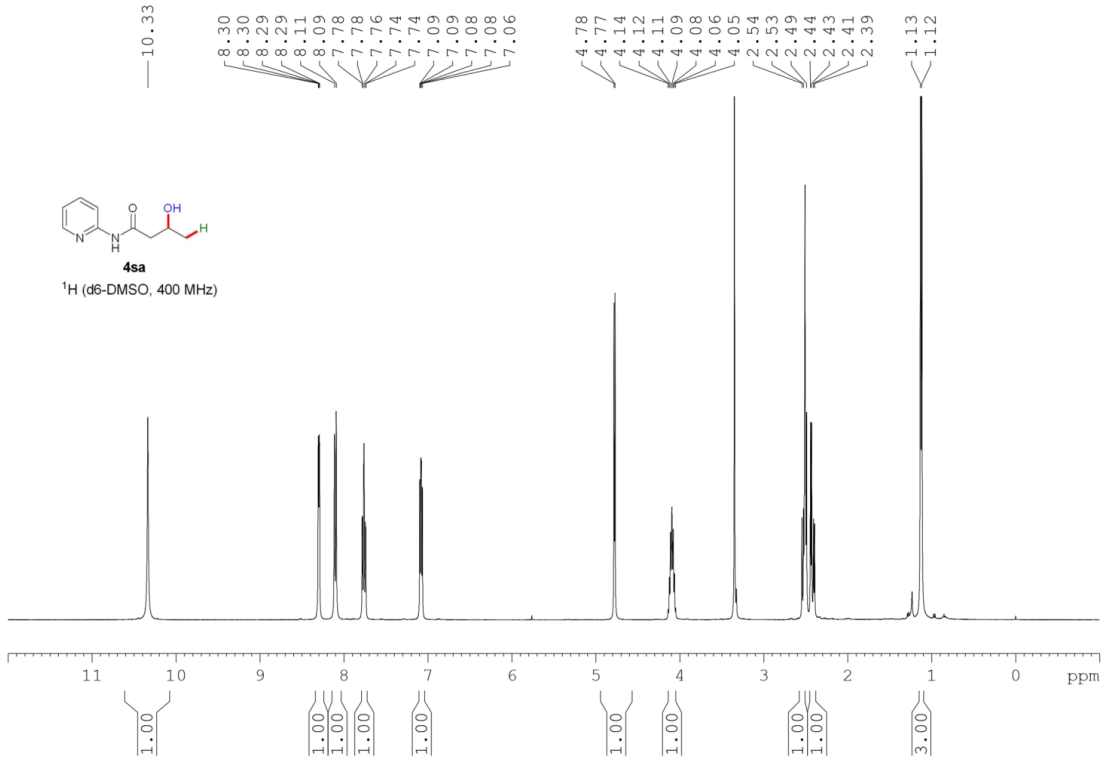
^{1}H NMR Spectra of **4ra**



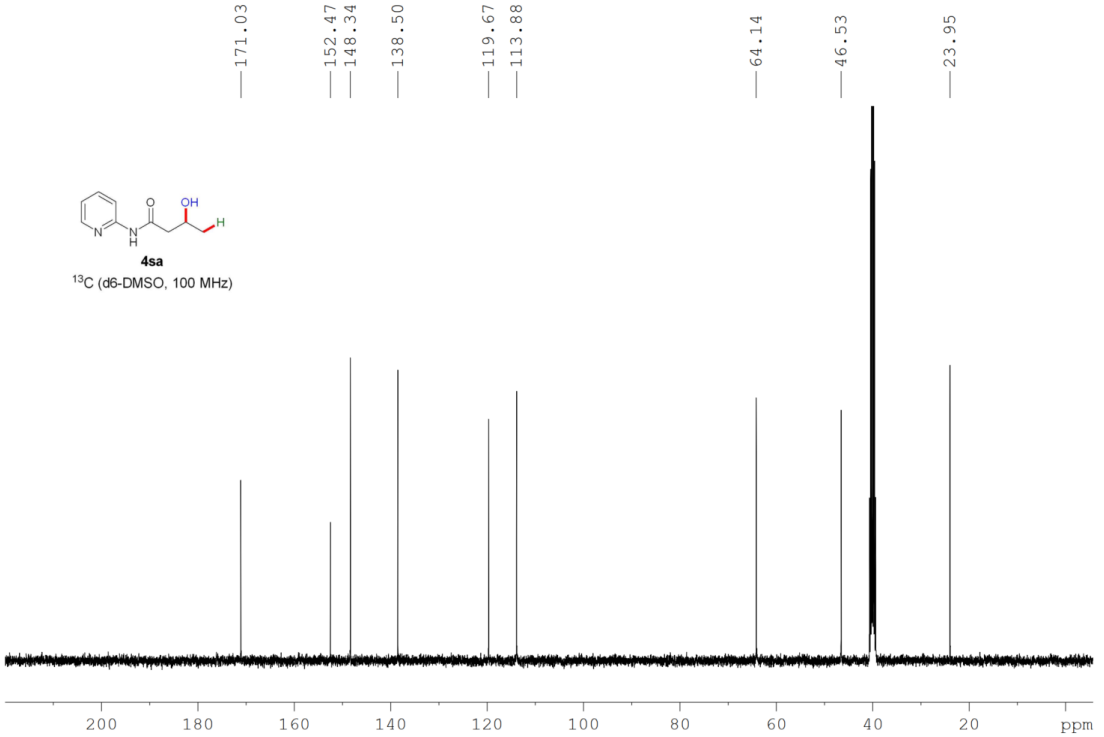
^{13}C NMR Spectra of **4ra**



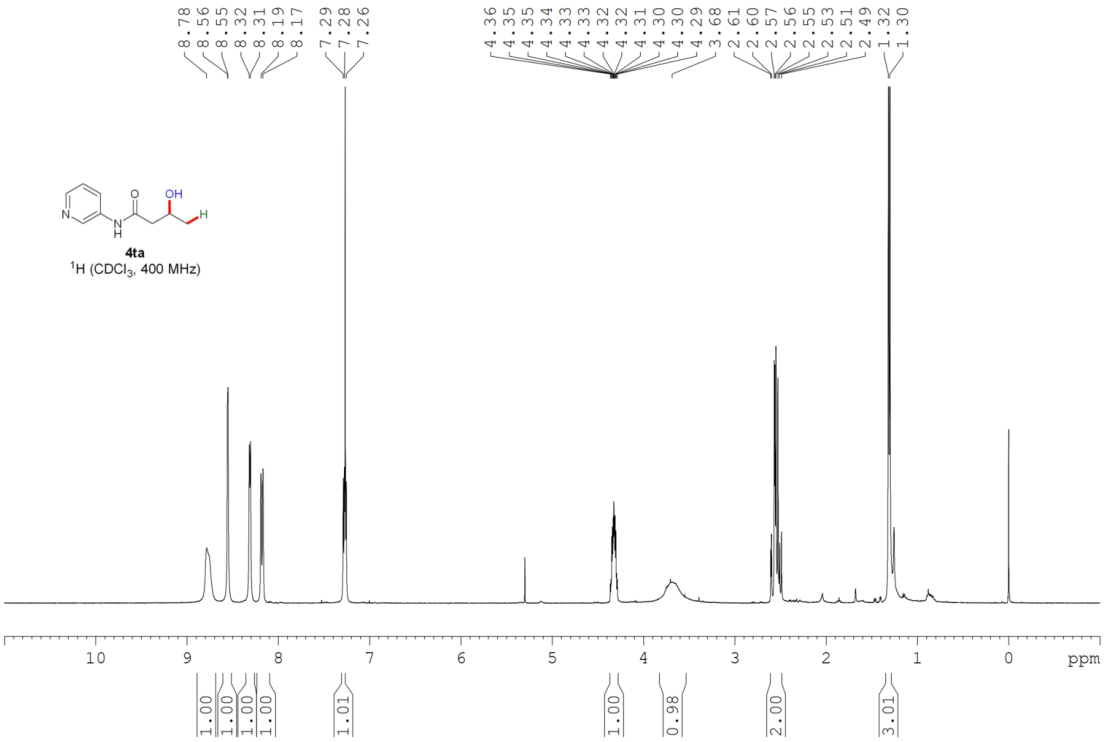
^{1}H NMR Spectra of **4sa**



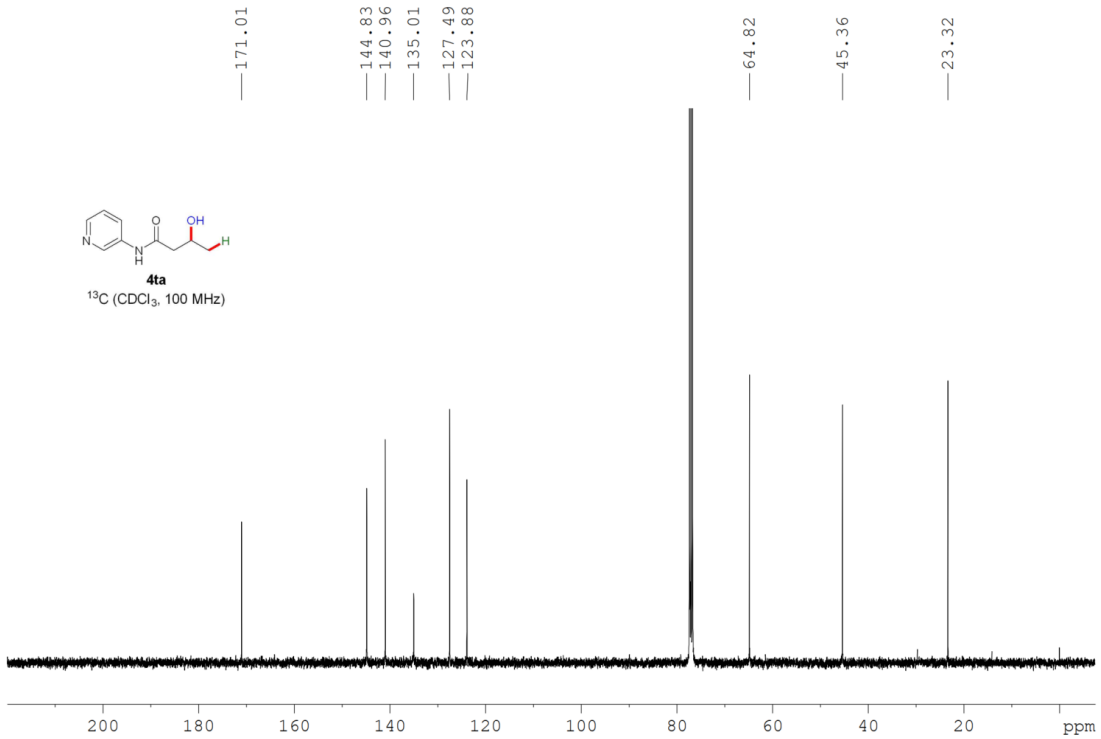
^{13}C NMR Spectra of **4sa**



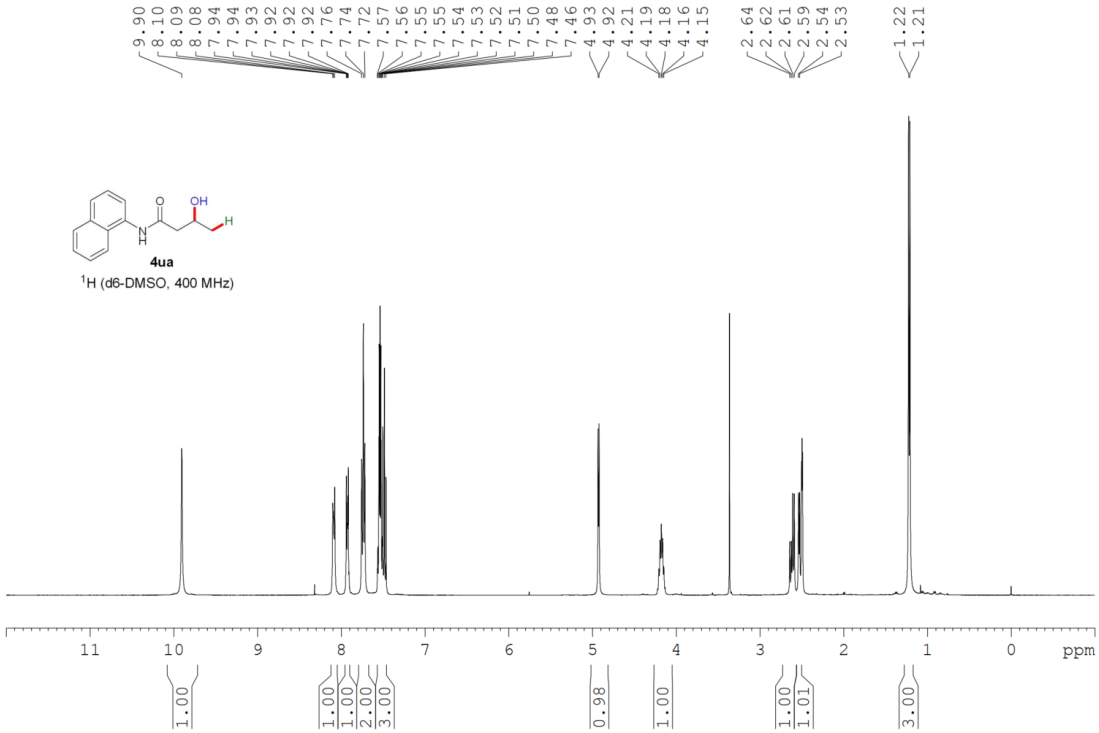
^{1}H NMR Spectra of **4ta**



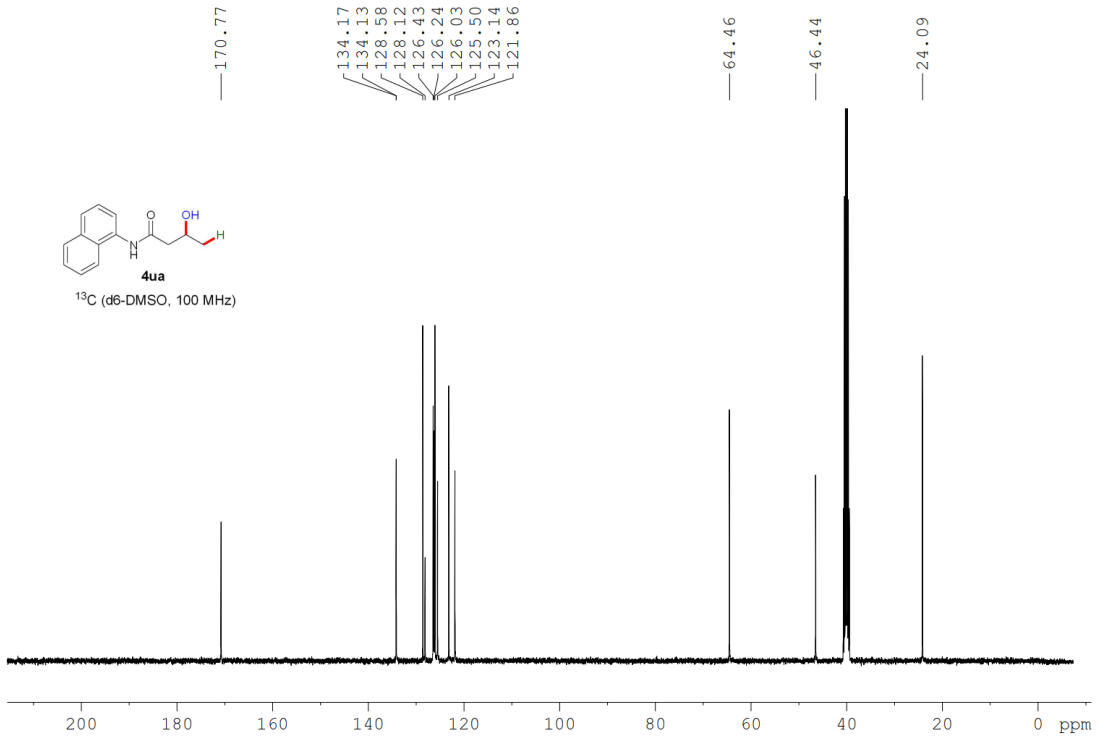
^{13}C NMR Spectra of **4ta**



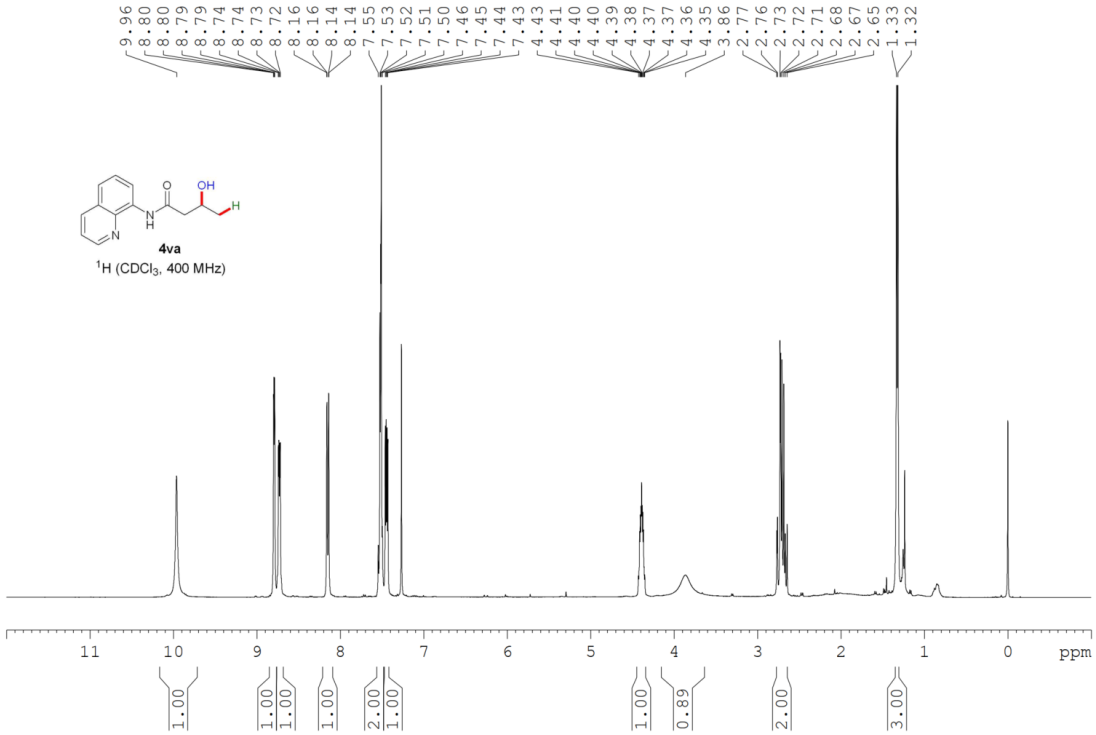
^{1}H NMR Spectra of **4ua**



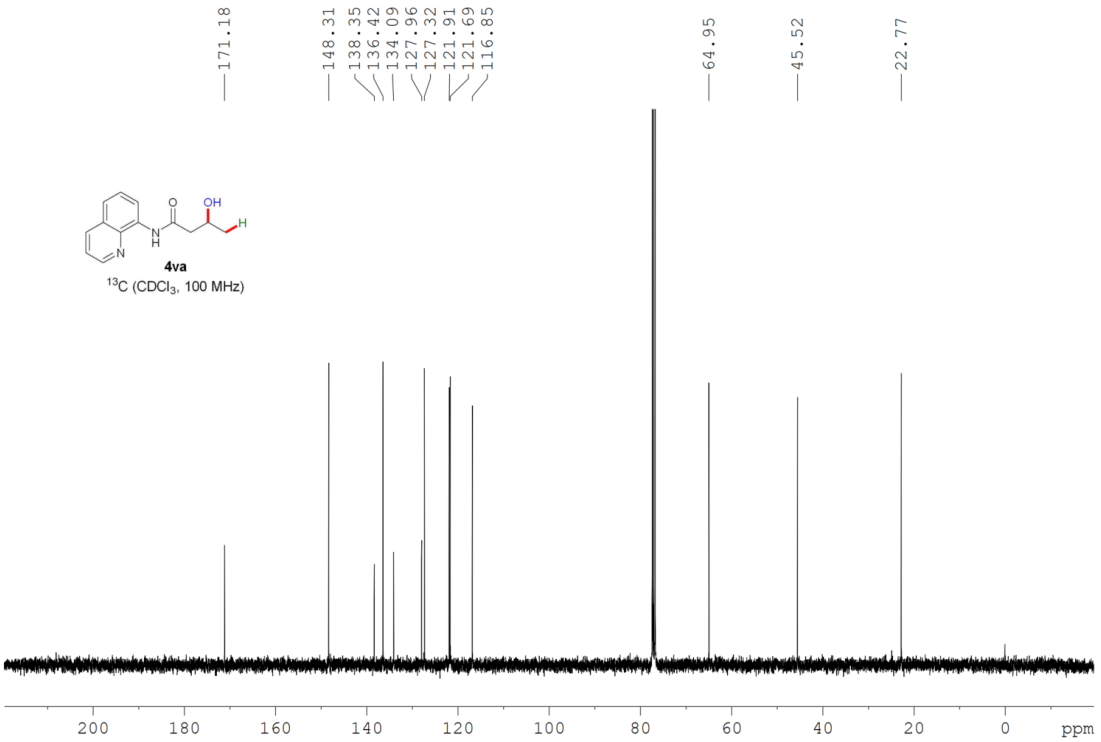
^{13}C NMR Spectra of **4ua**



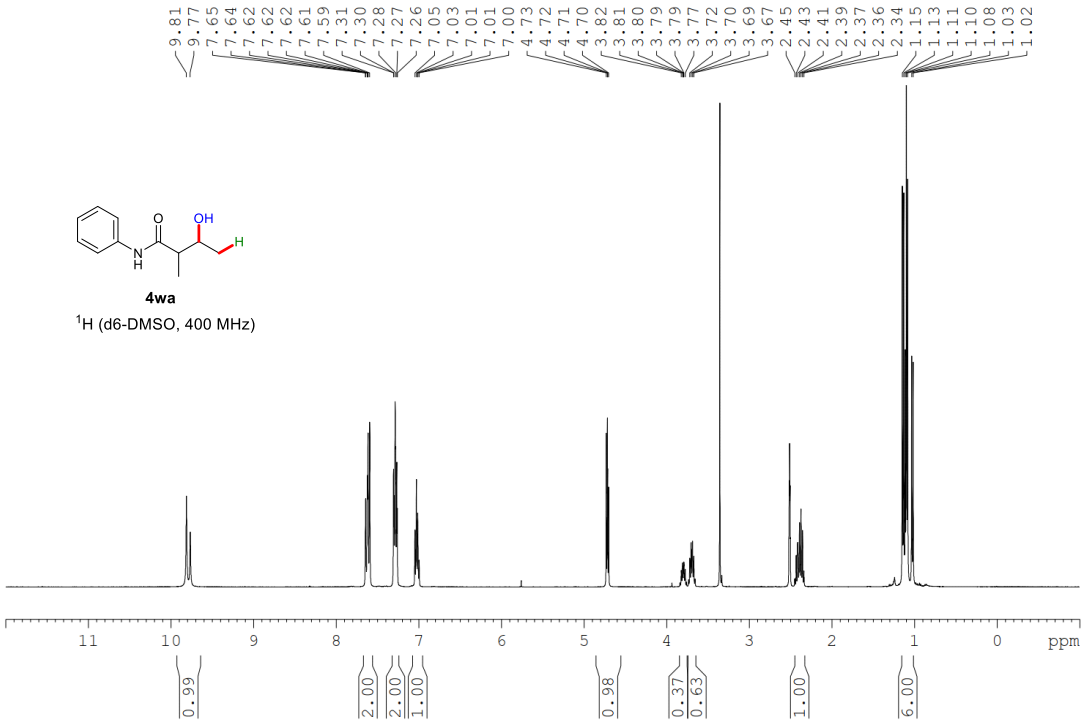
^{1}H NMR Spectra of **4va**



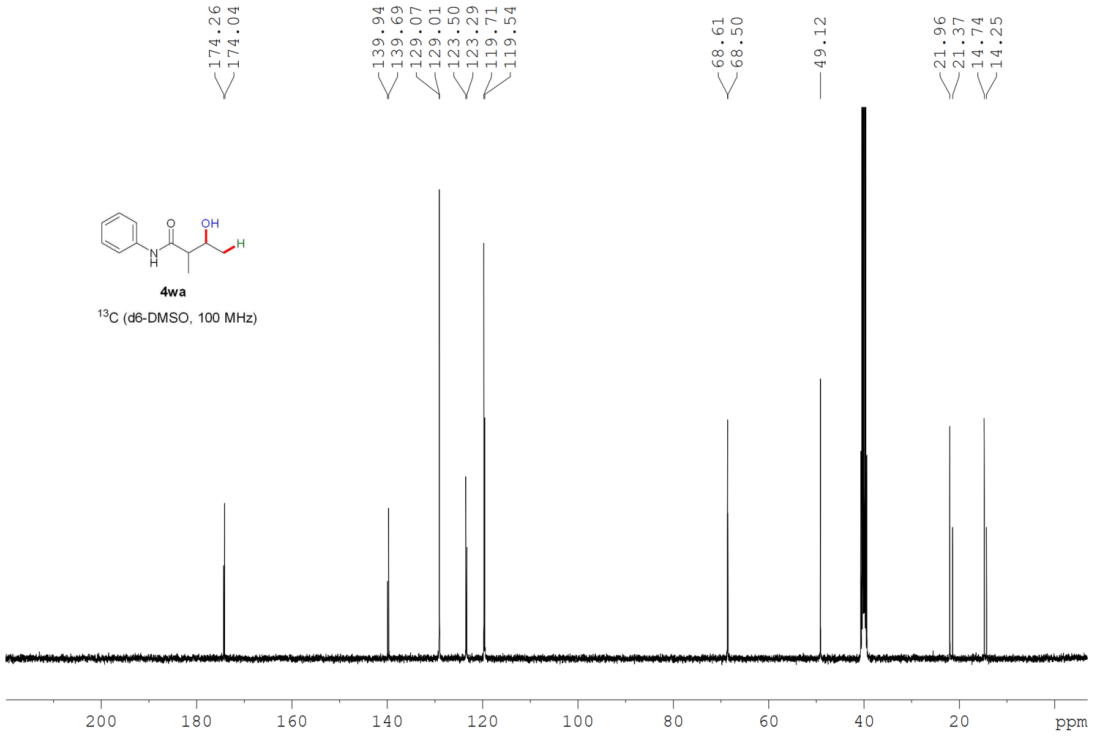
^{13}C NMR Spectra of **4va**



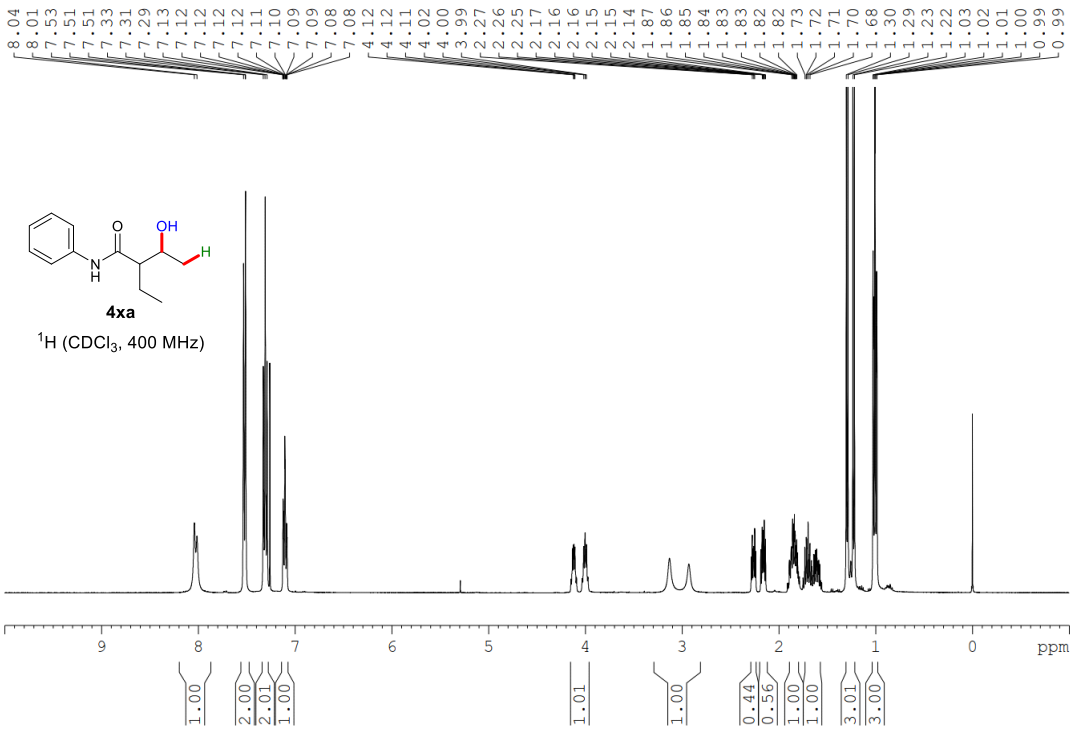
^{1}H NMR Spectra of **4wa**



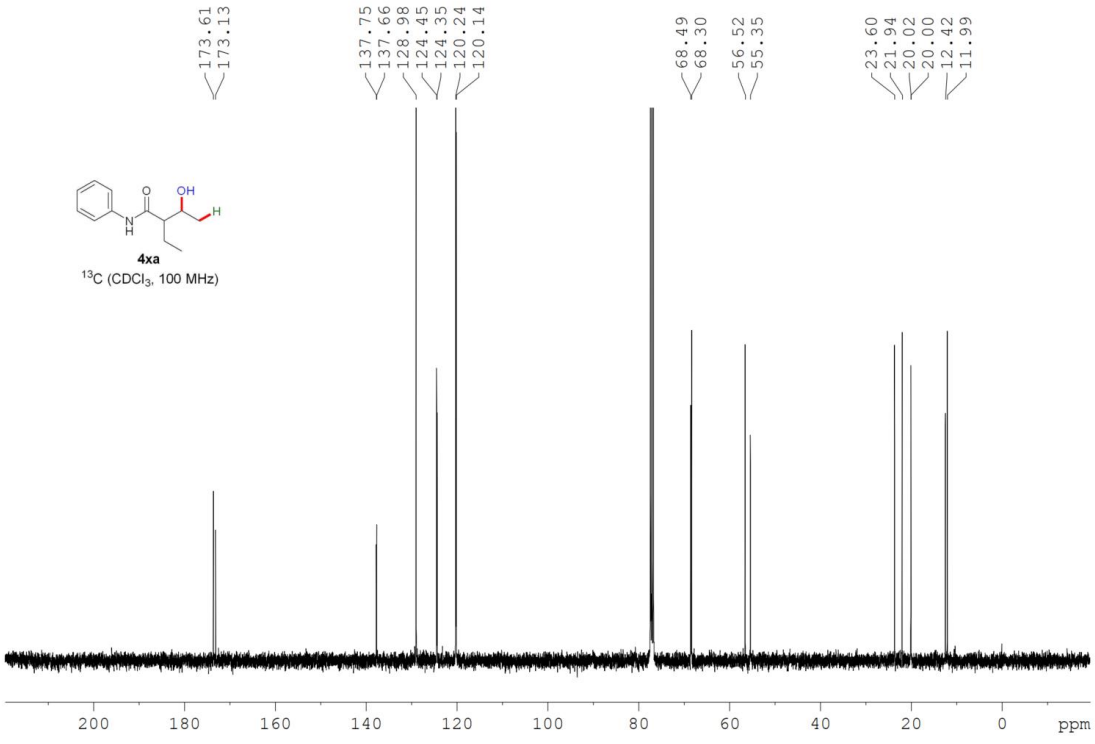
^{13}C NMR Spectra of **4wa**



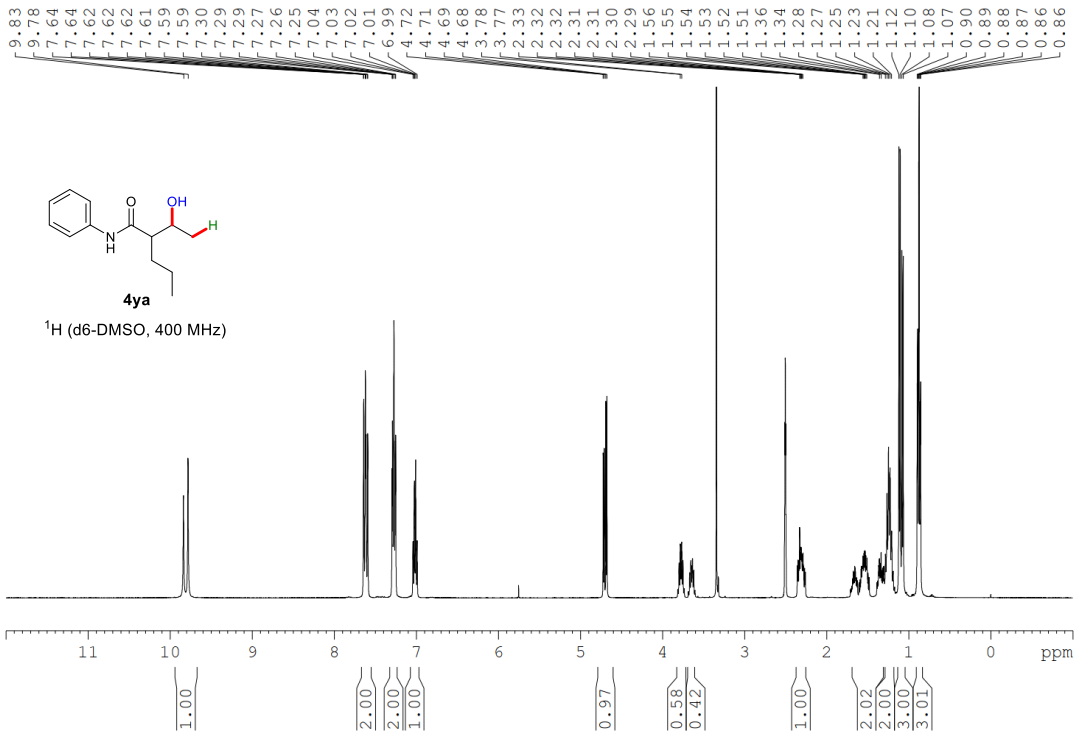
^{1}H NMR Spectra of **4xa**



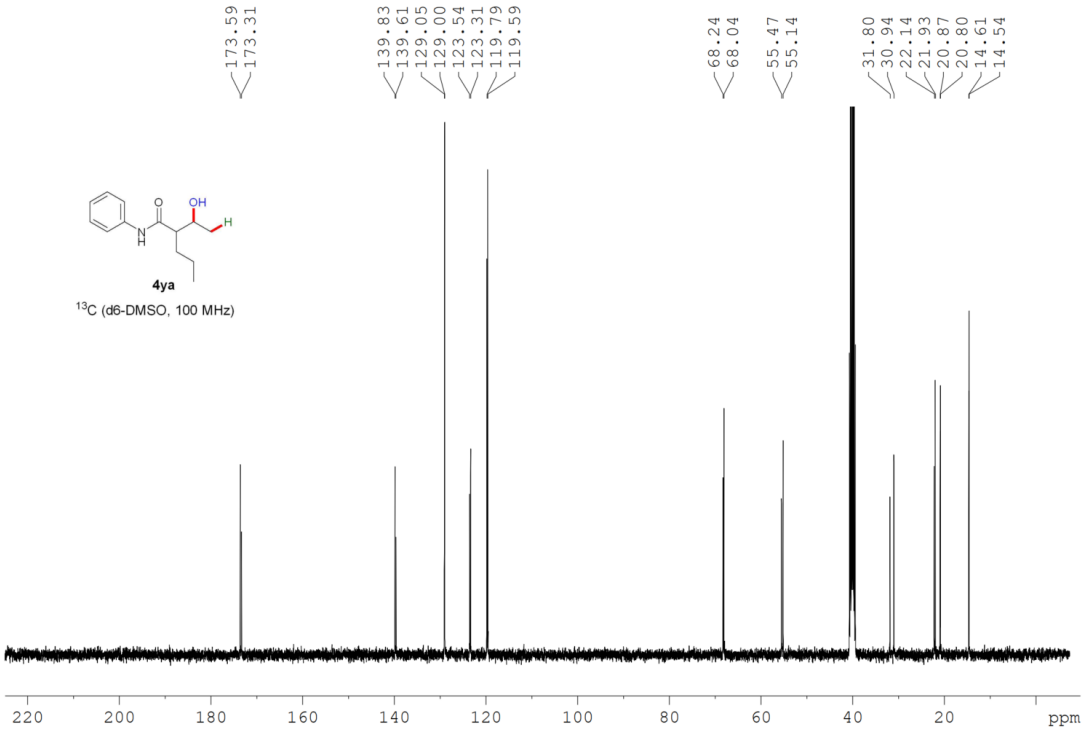
^{13}C NMR Spectra of **4xa**



^{1}H NMR Spectra of **4ya**



^{13}C NMR Spectra of **4ya**



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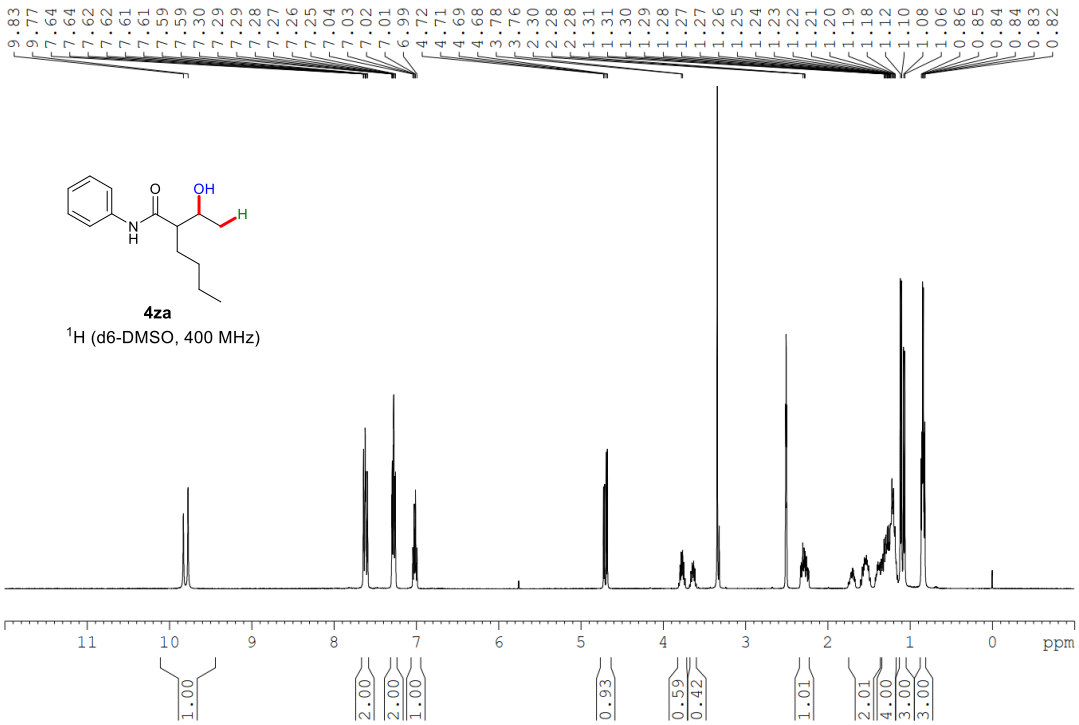

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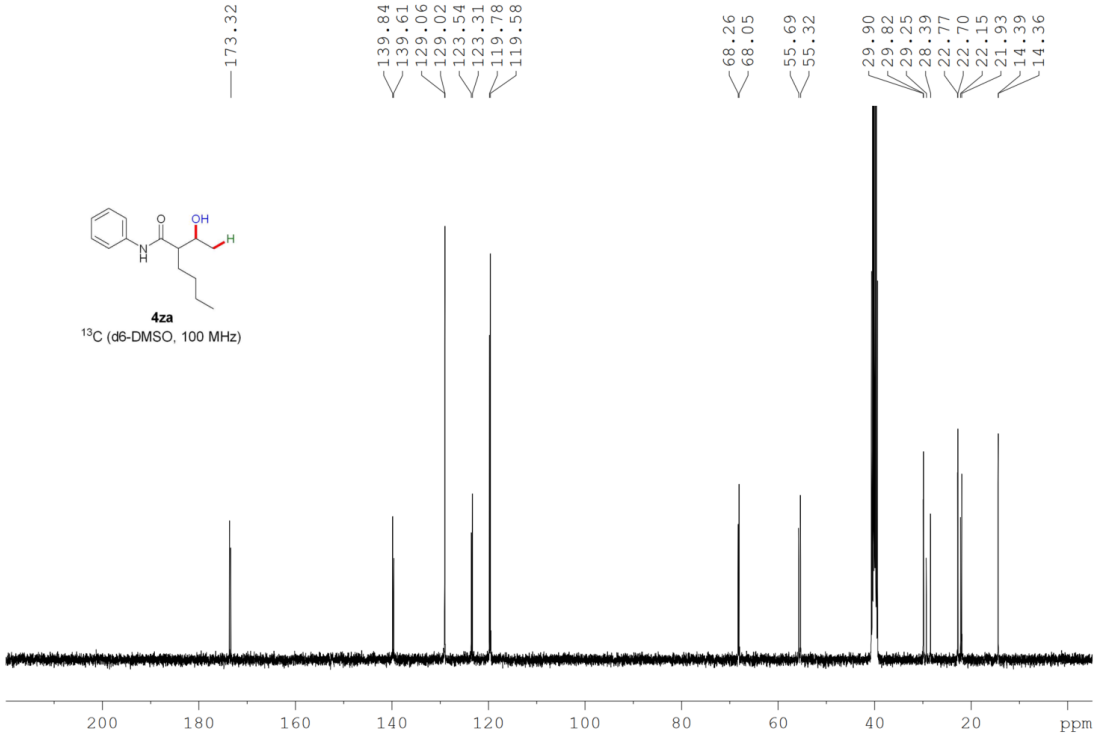
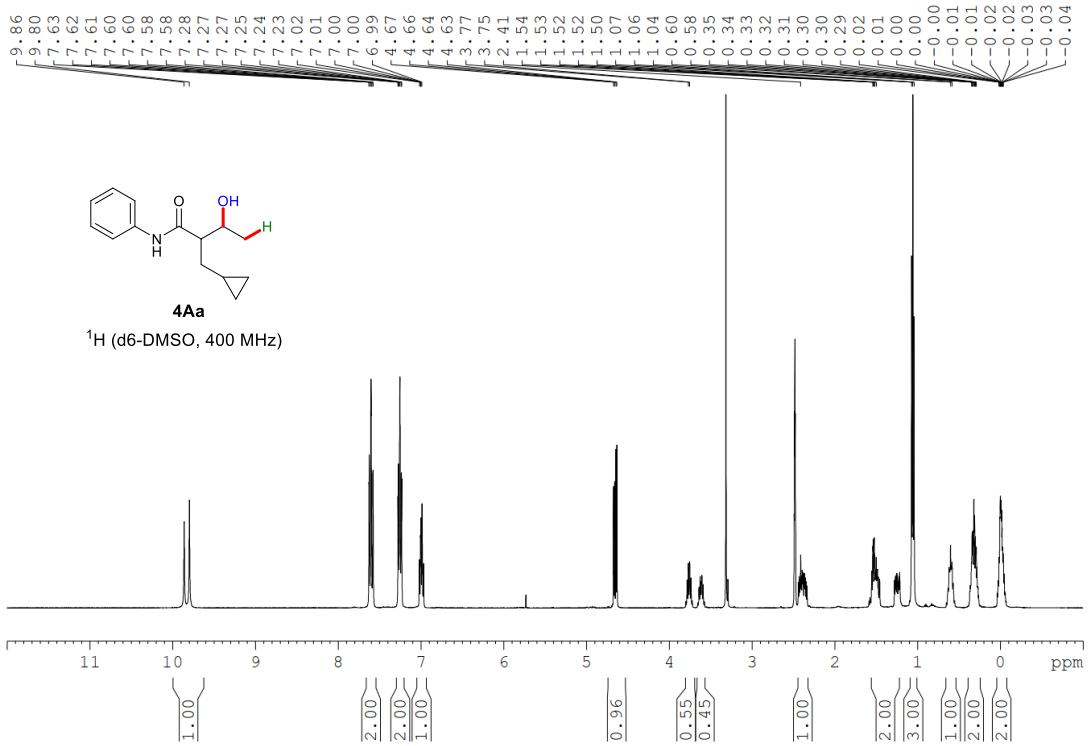
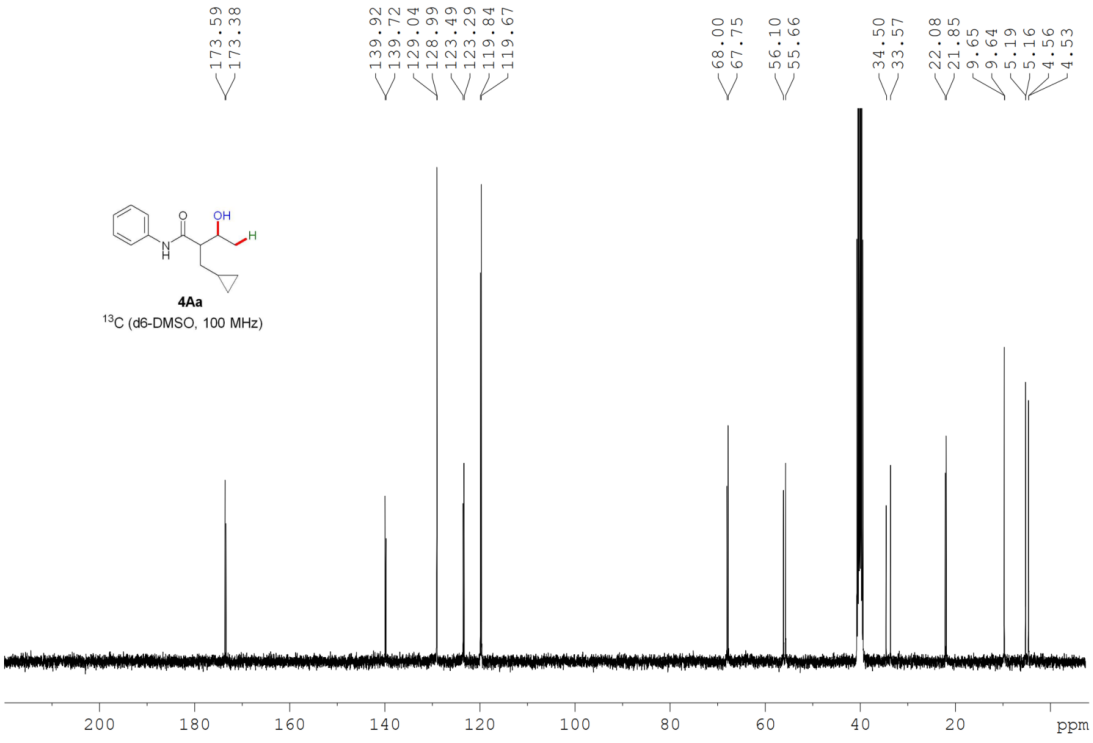


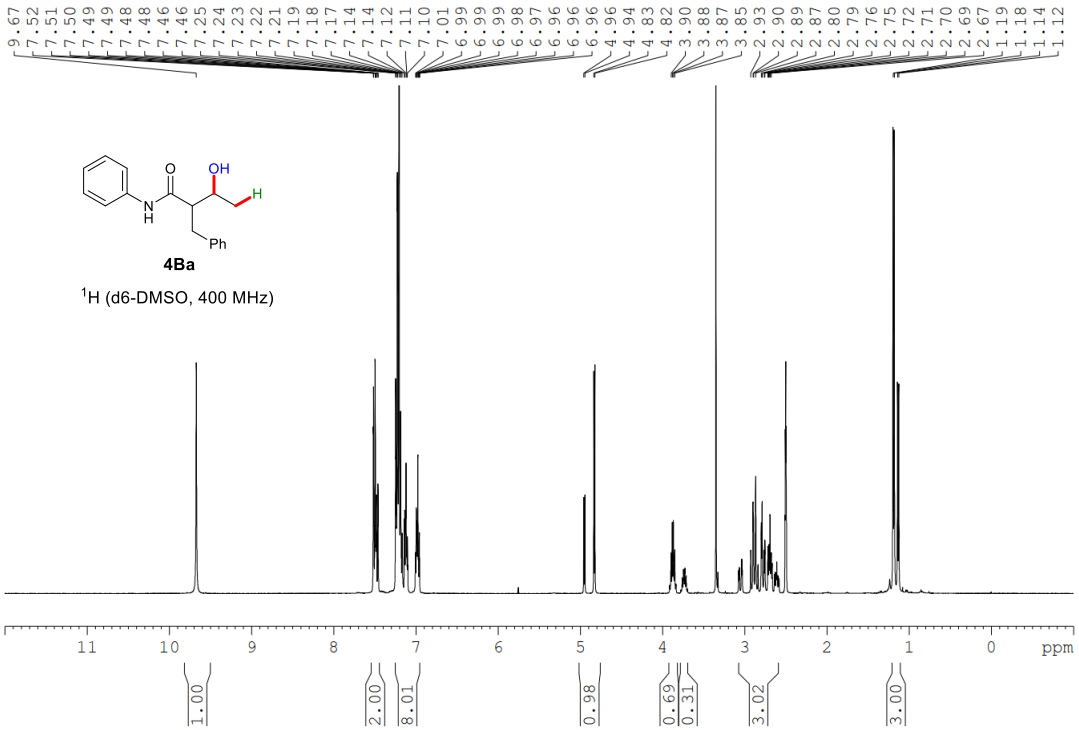
^{1}H NMR Spectra of **4Aa**



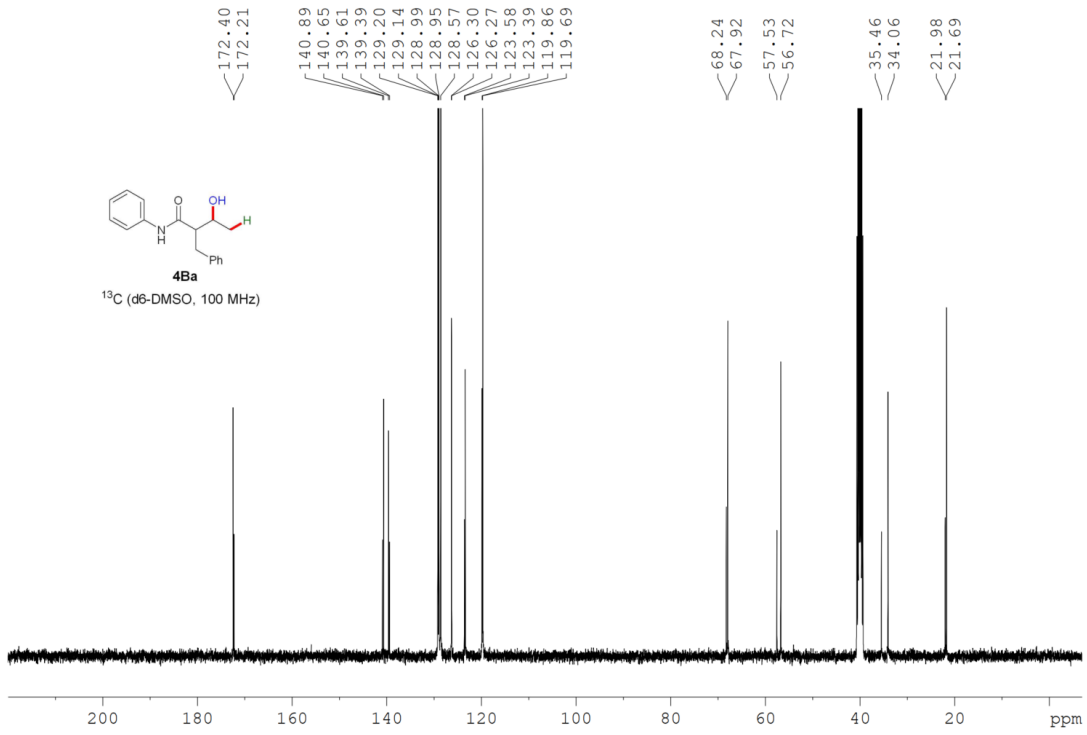
^{13}C NMR Spectra of **4Aa**



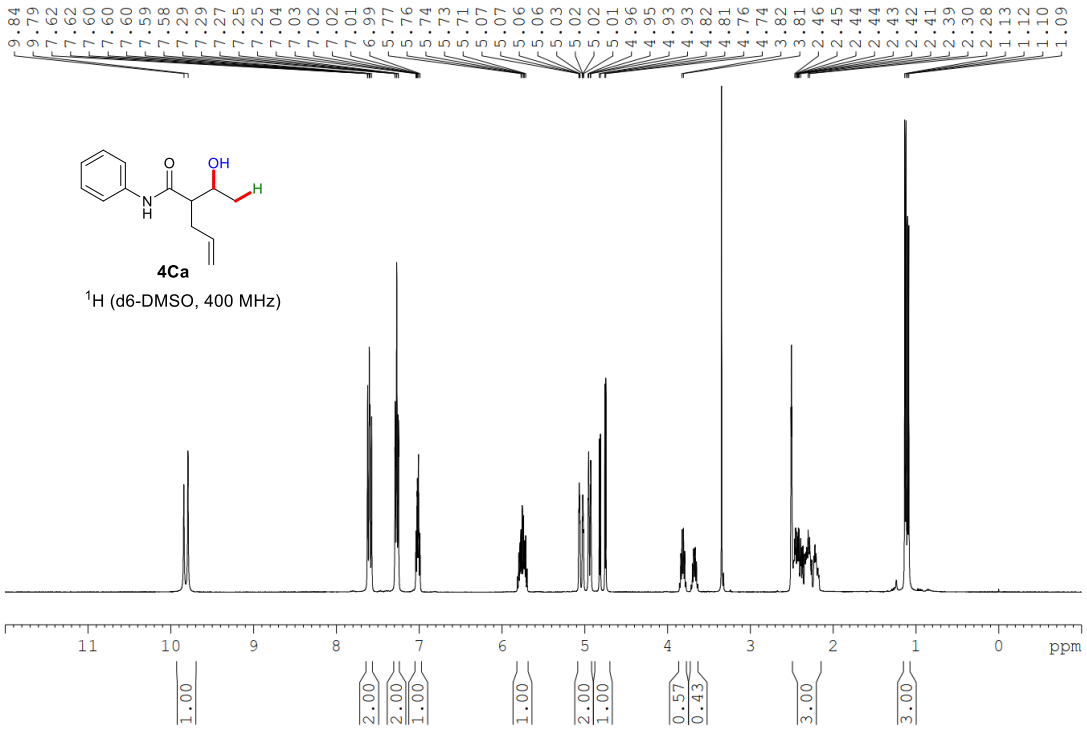
^{1}H NMR Spectra of **4Ba**



^{13}C NMR Spectra of **4Ba**



^{1}H NMR Spectra of **4Ca**



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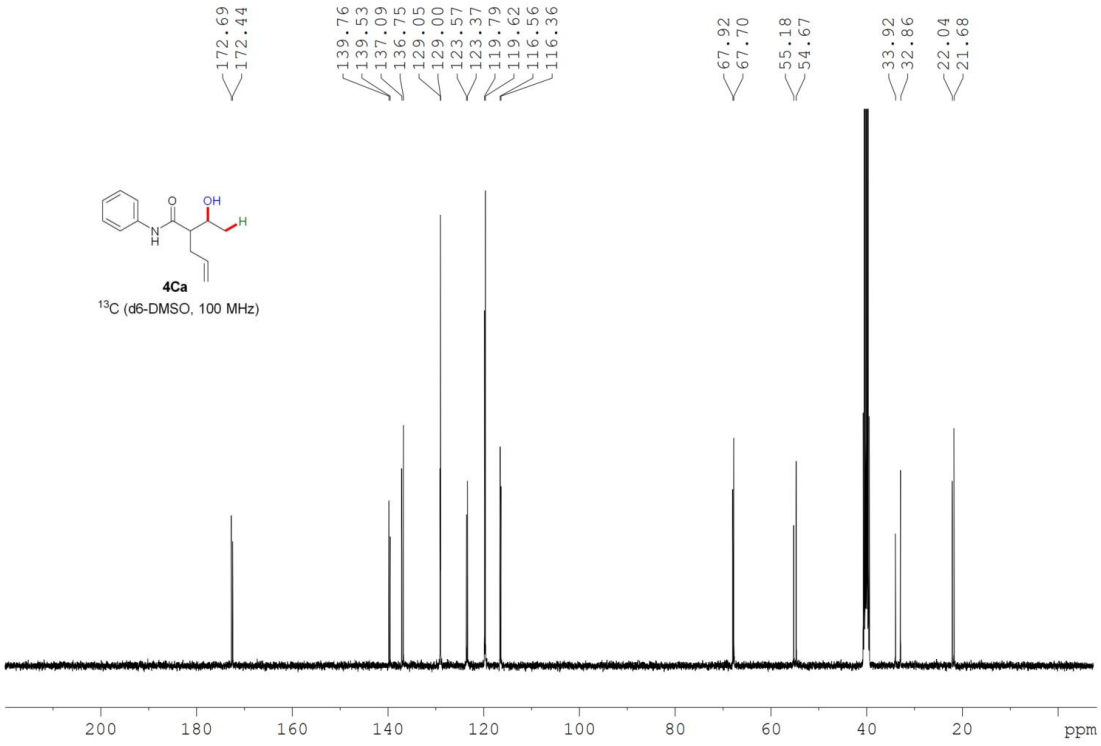
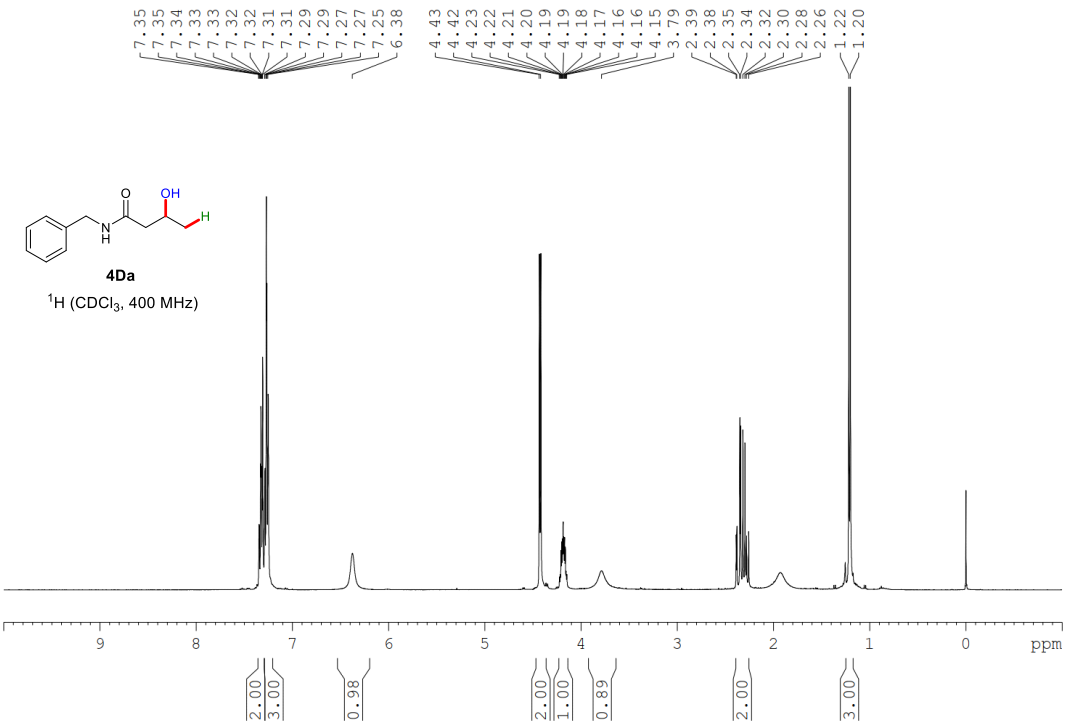
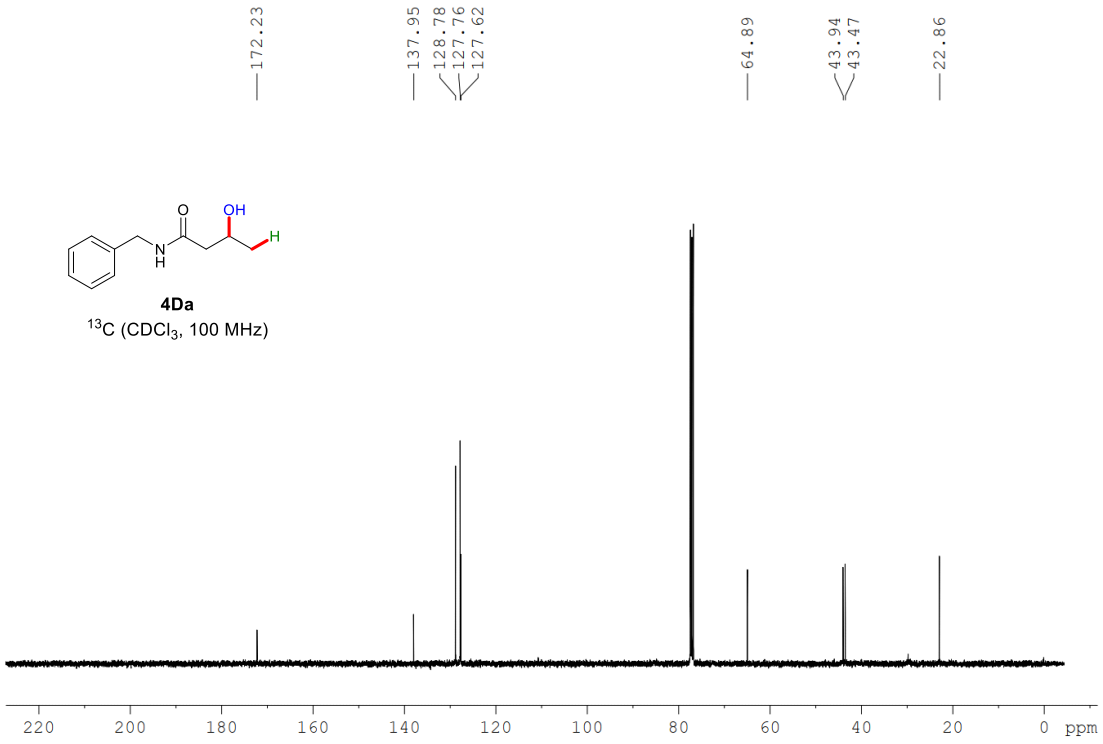


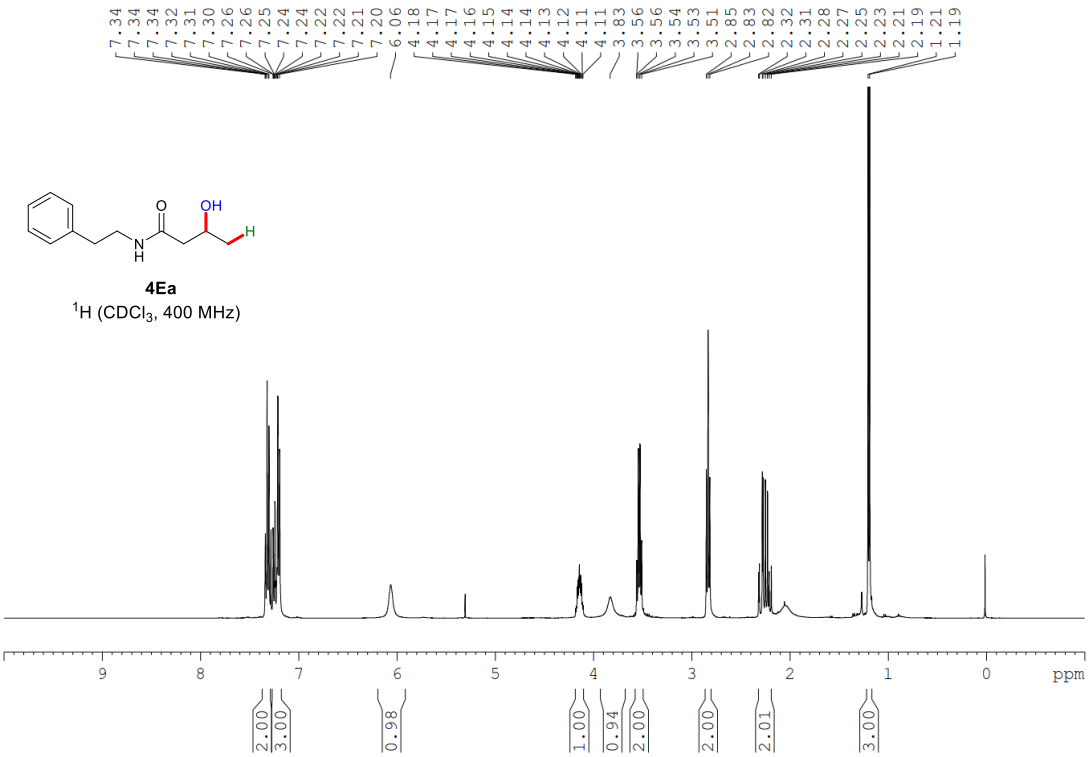
^{1}H NMR Spectra of **4Da**



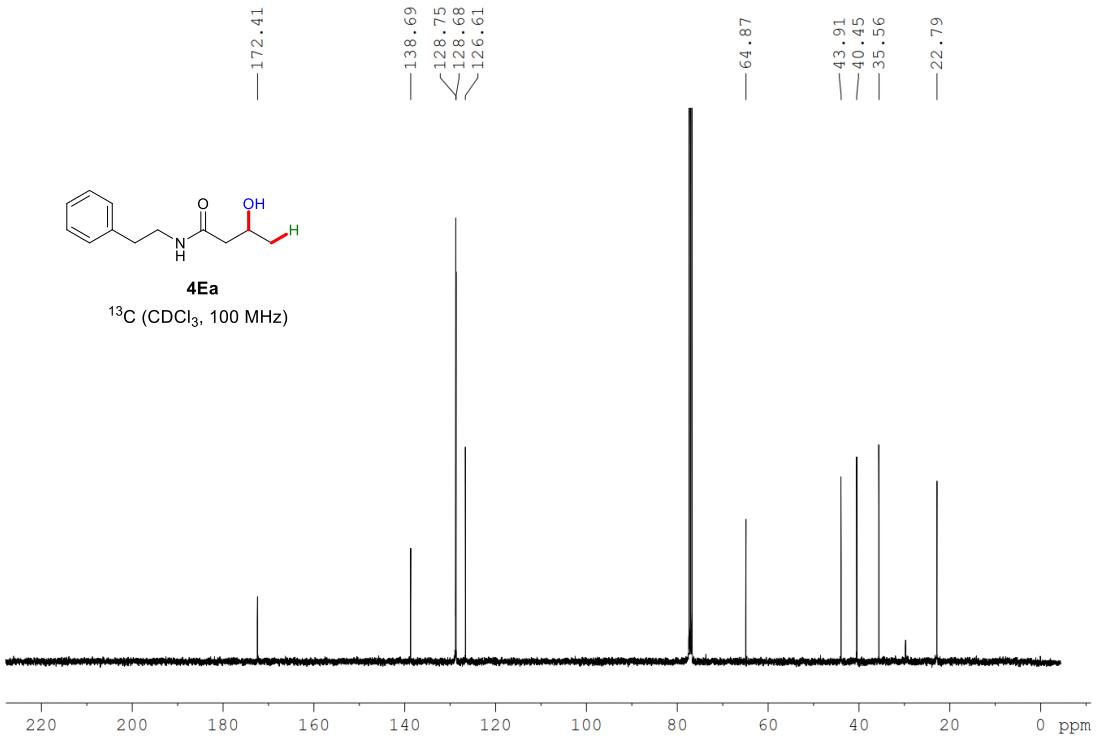
^{13}C NMR Spectra of **4Da**



^{1}H NMR Spectra of **4Ea**



^{13}C NMR Spectra of **4Ea**



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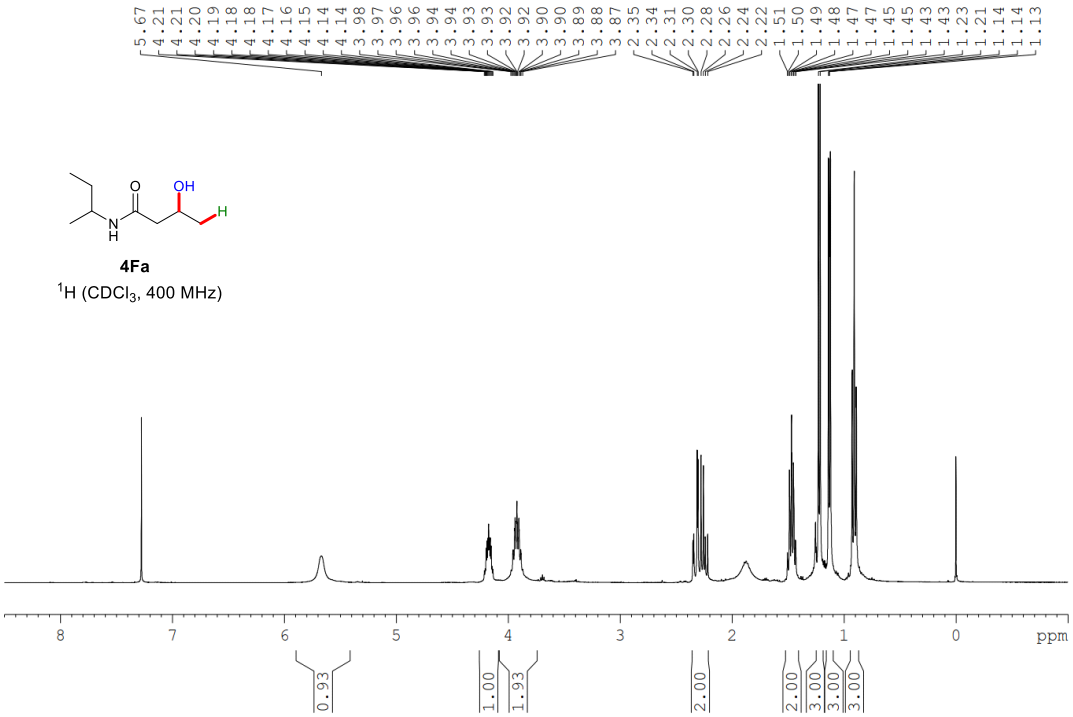
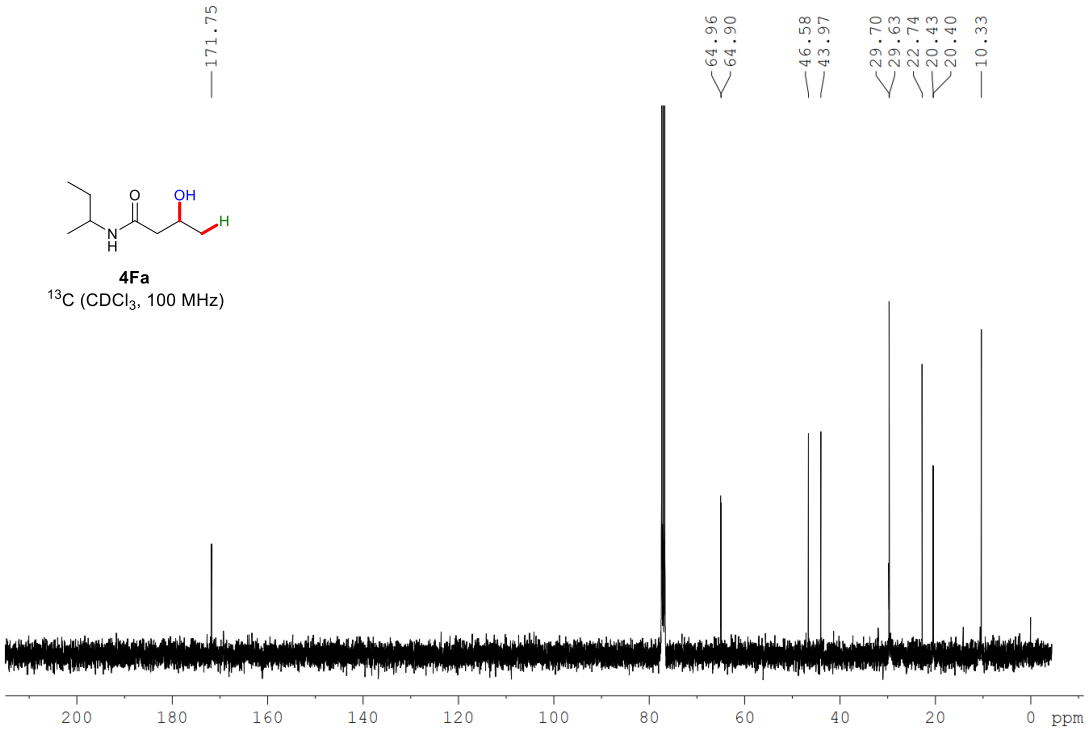
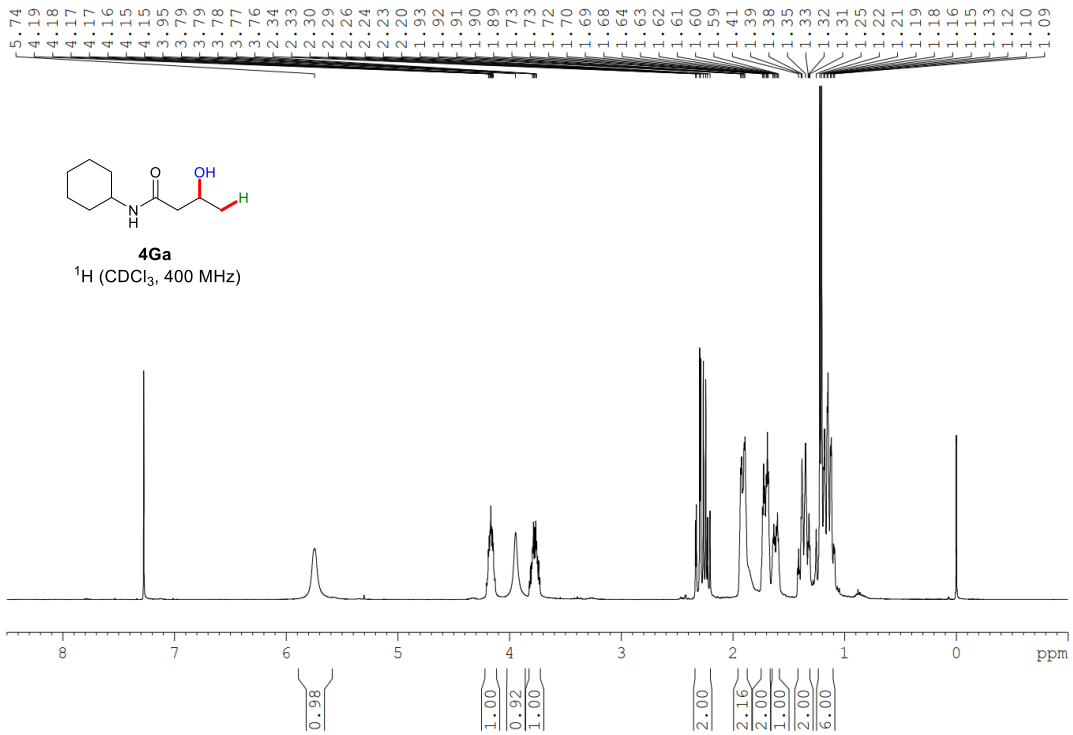


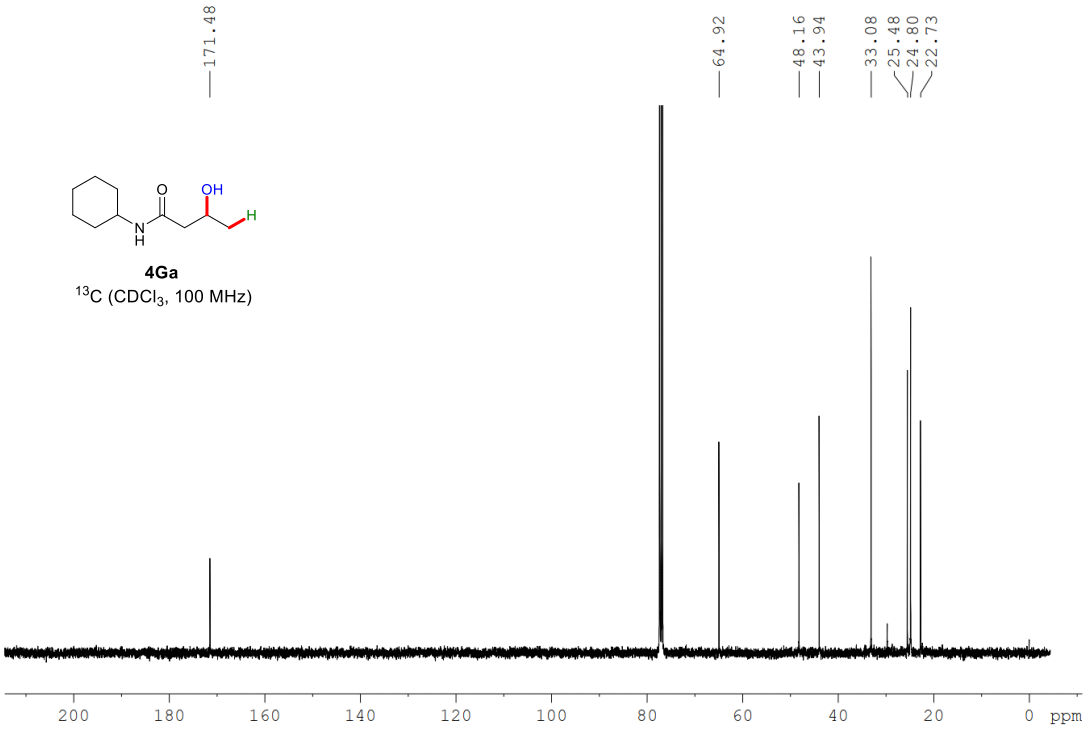
^{13}C NMR Spectra of **4Fa**



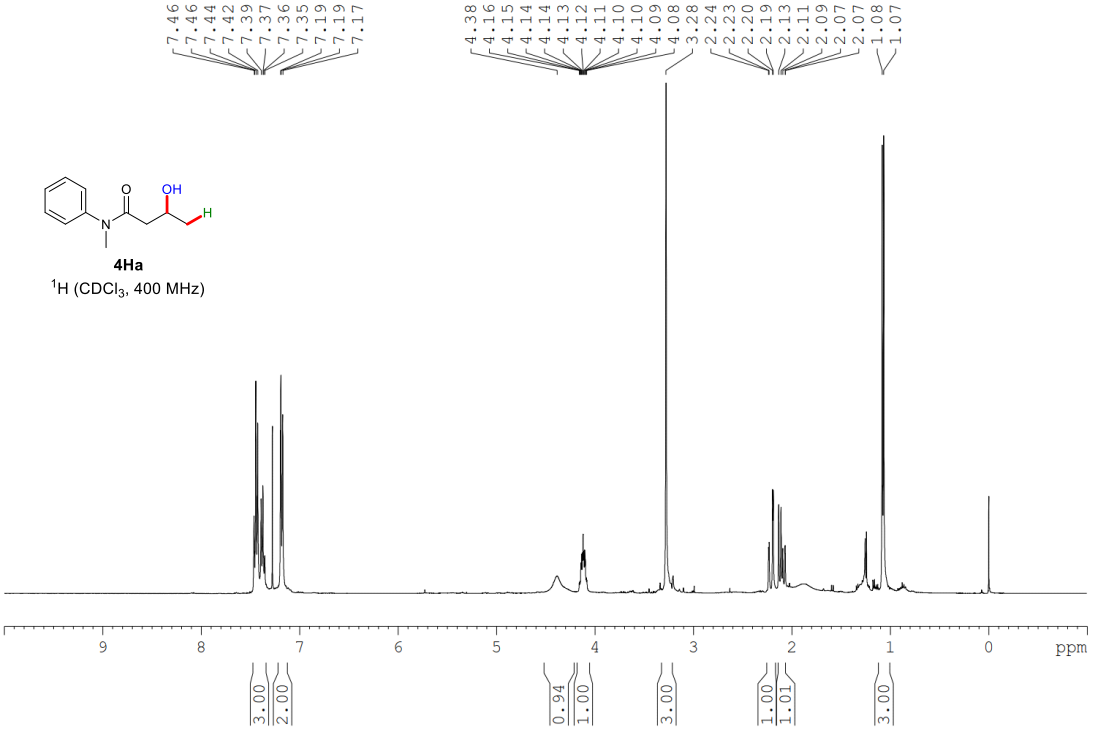
^{1}H NMR Spectra of **4Ga**



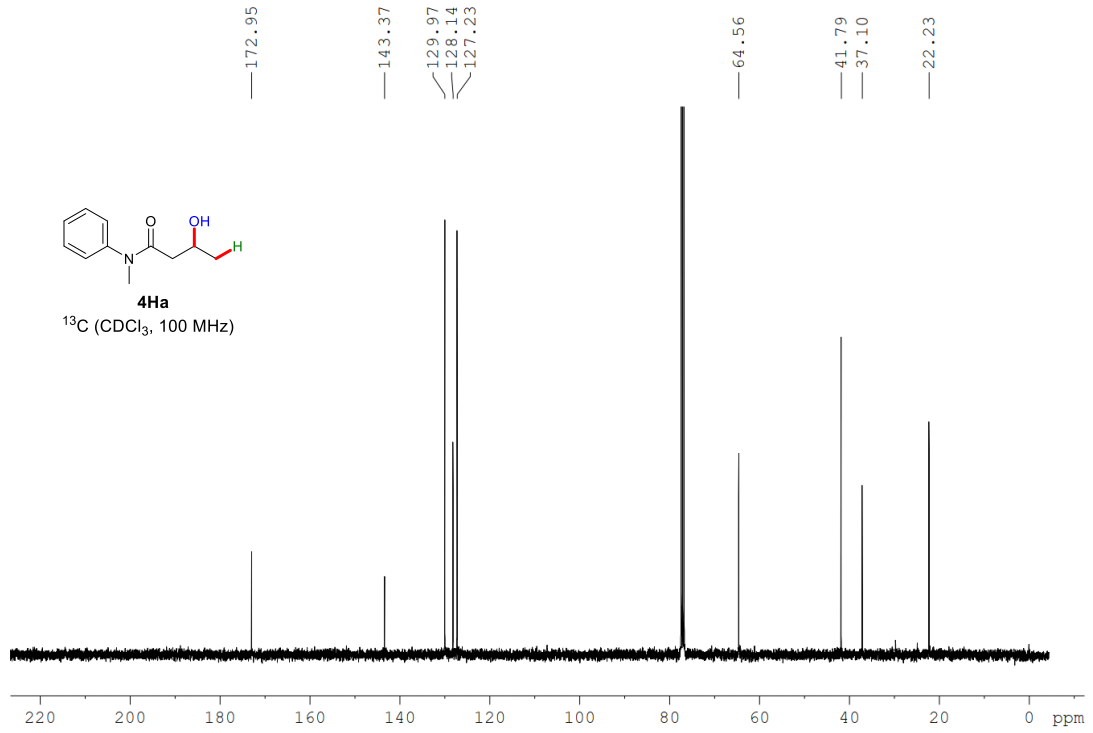
^{13}C NMR Spectra of **4Ga**



^{1}H NMR Spectra of **4Ha**



^{13}C NMR Spectra of **4Ha**



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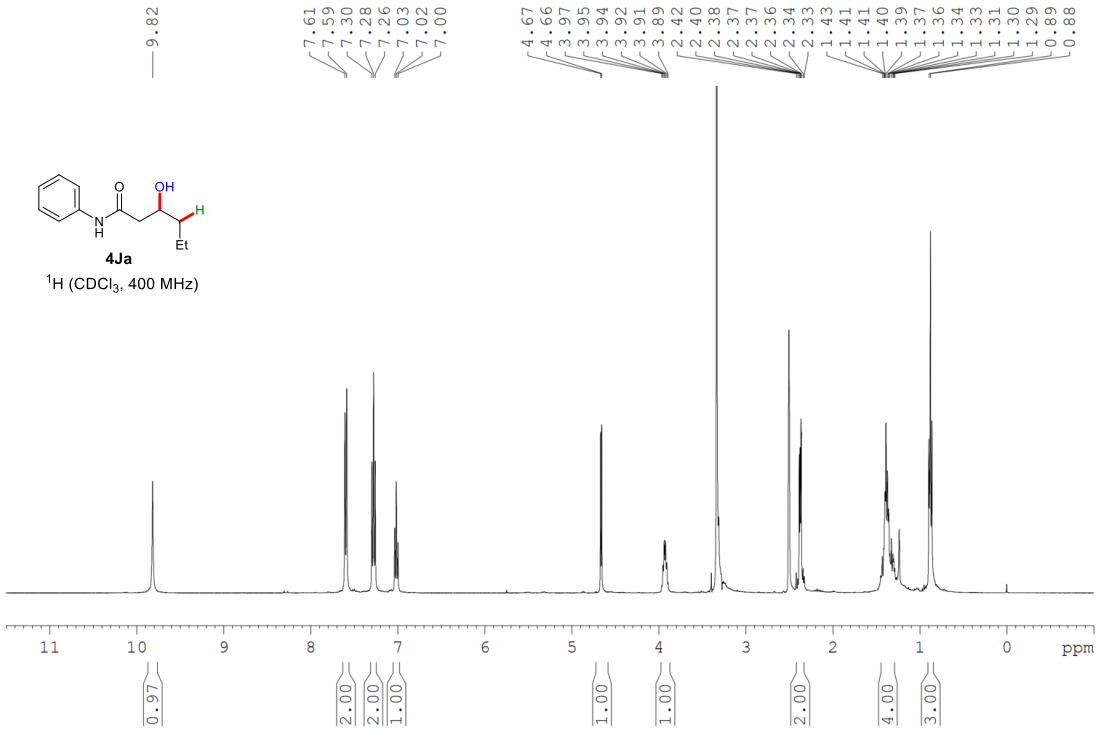
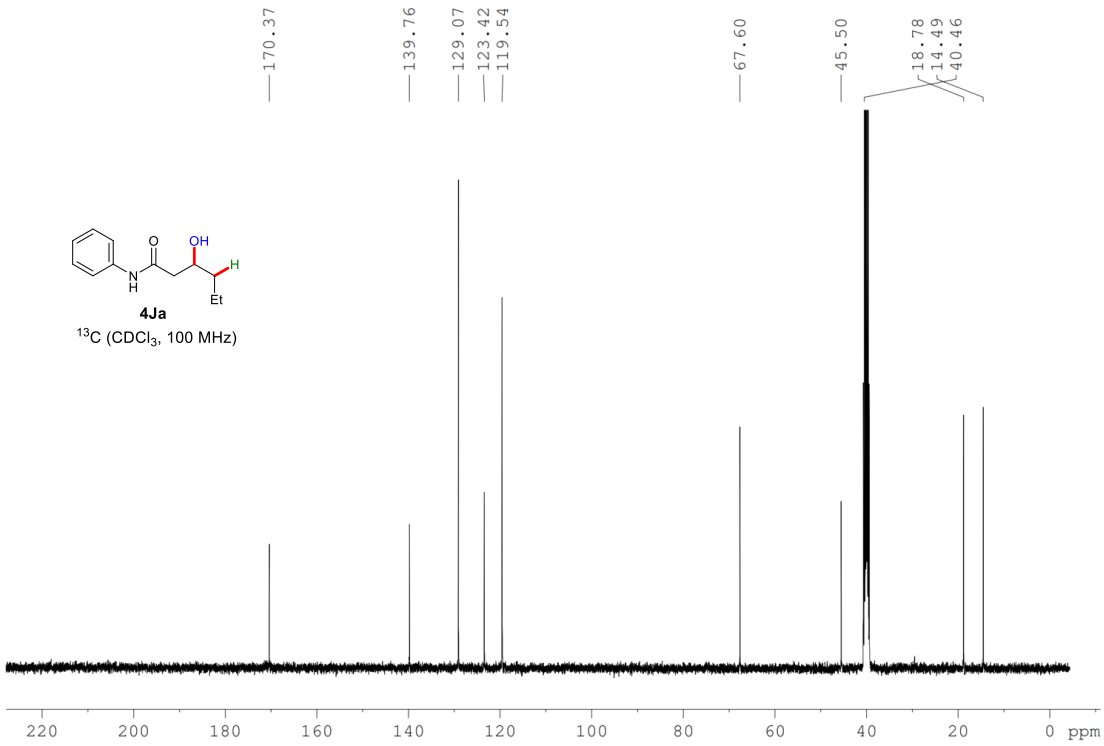
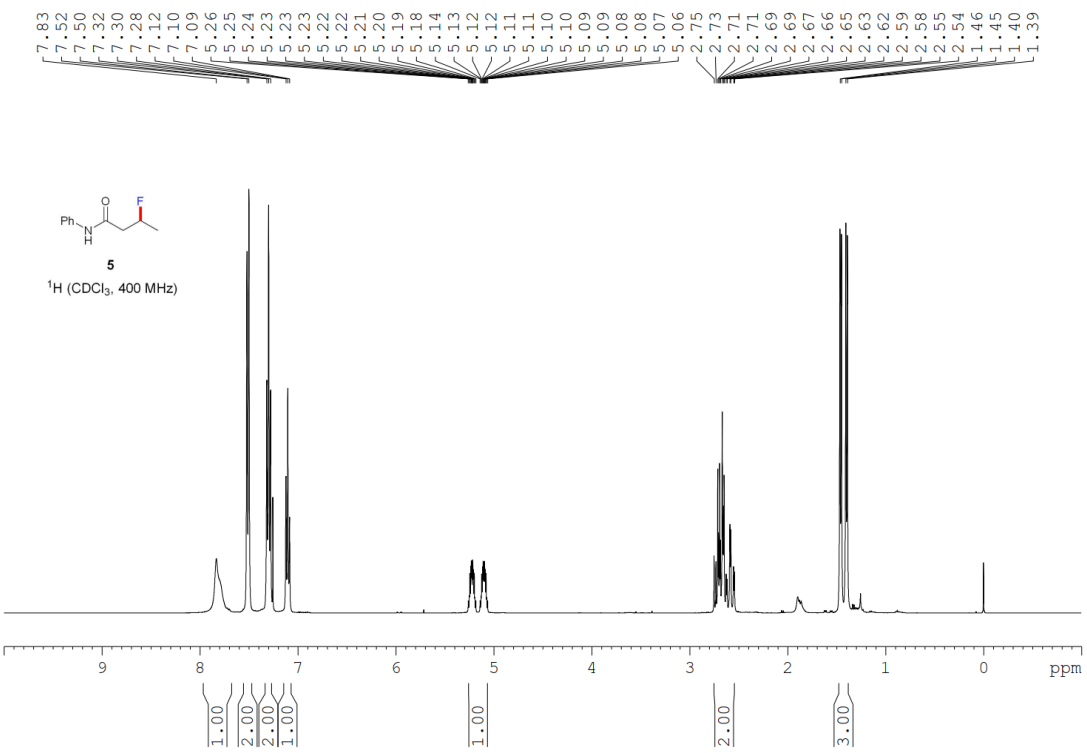


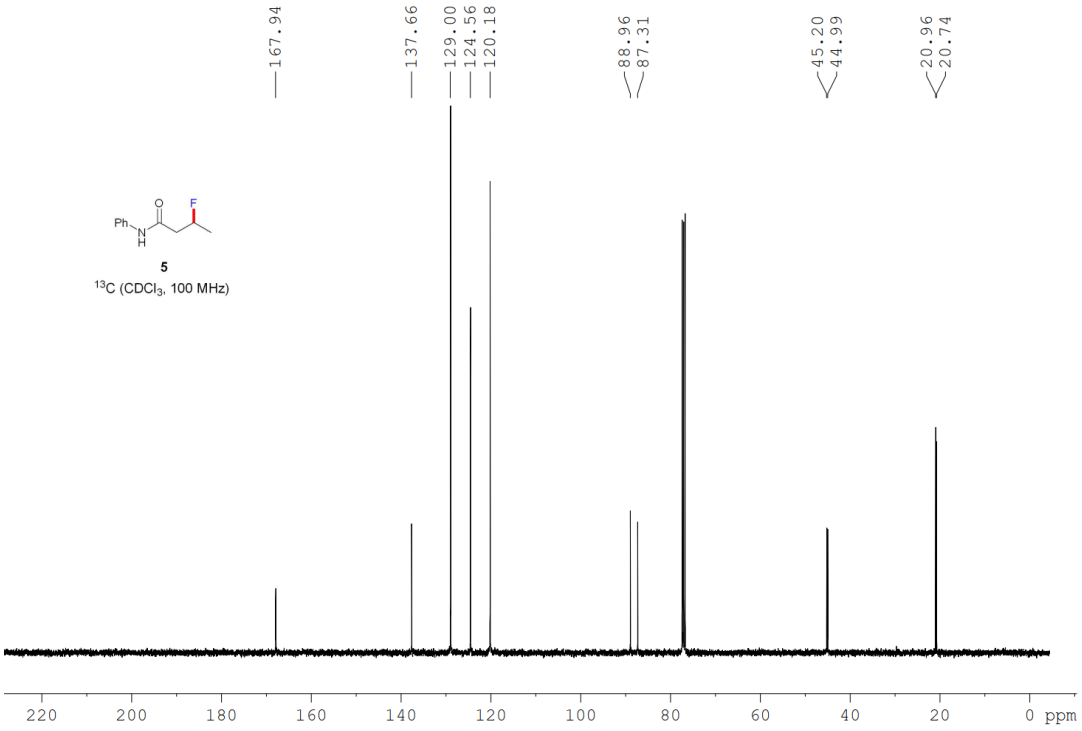
^{13}C NMR Spectra of **4Ja**



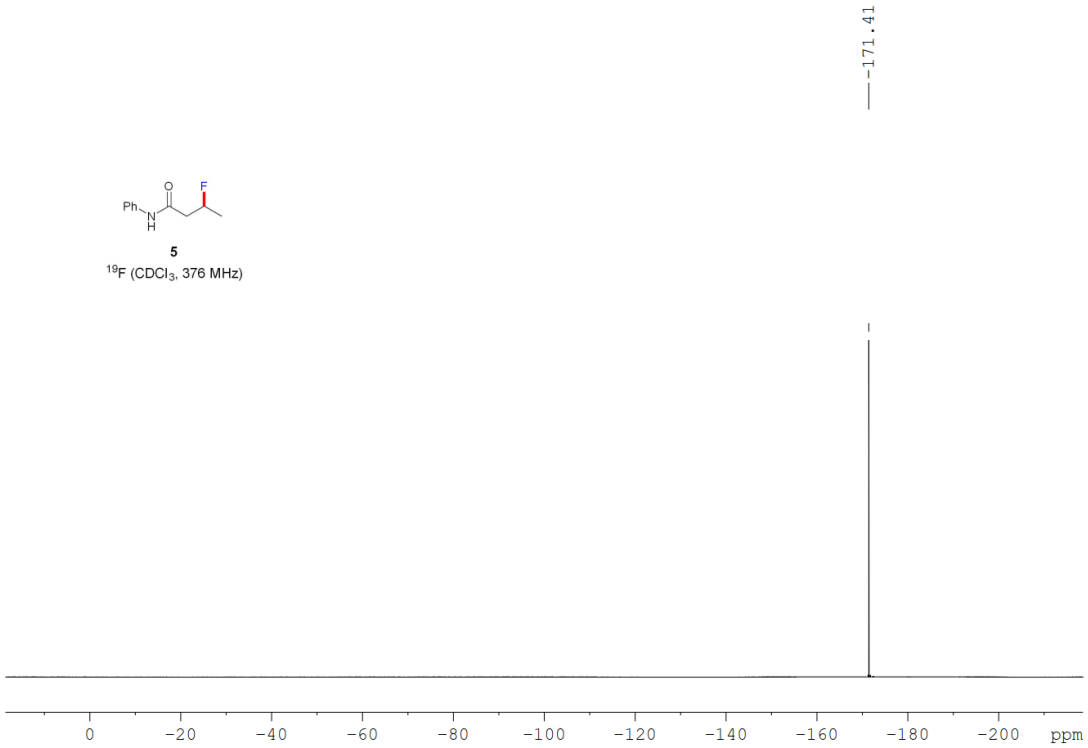
^{1}H NMR Spectra of **5**



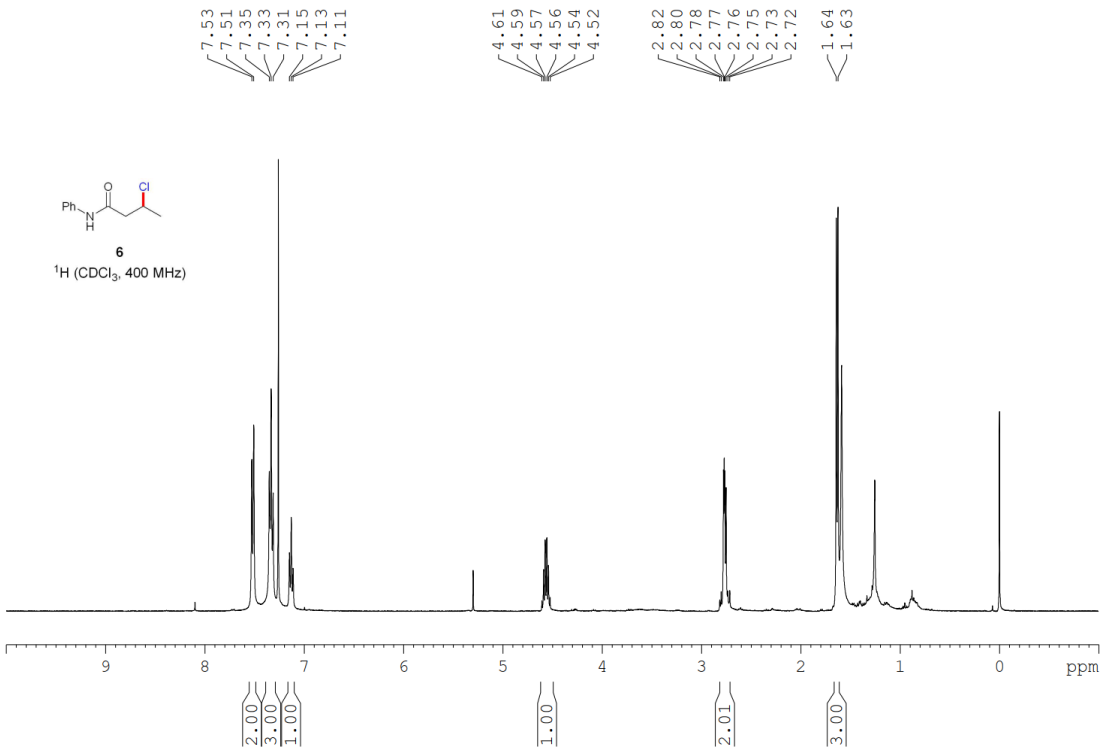
^{13}C NMR Spectra of **5**



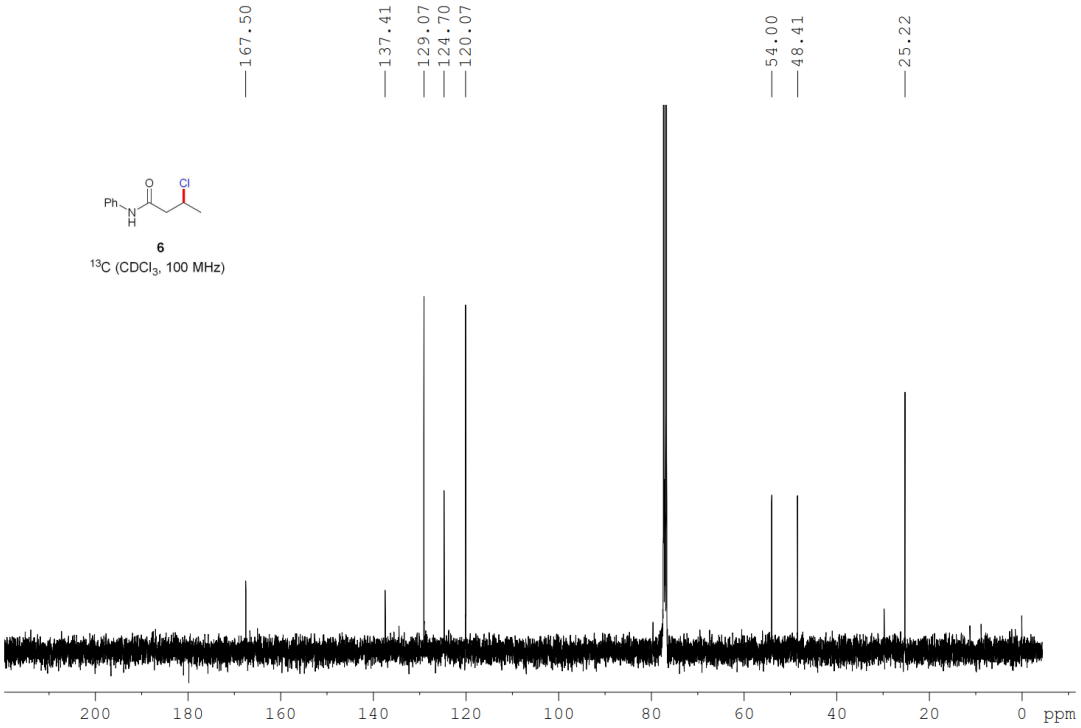
^{19}F NMR Spectra of **5**



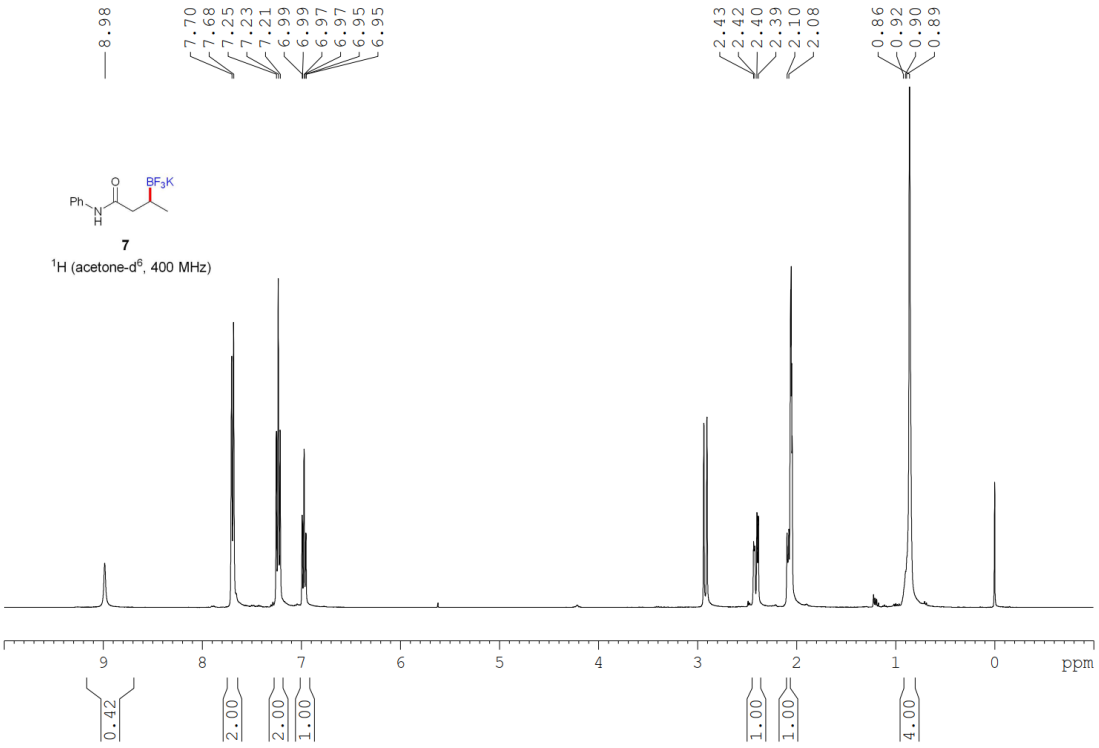
^{1}H NMR Spectra of **6**



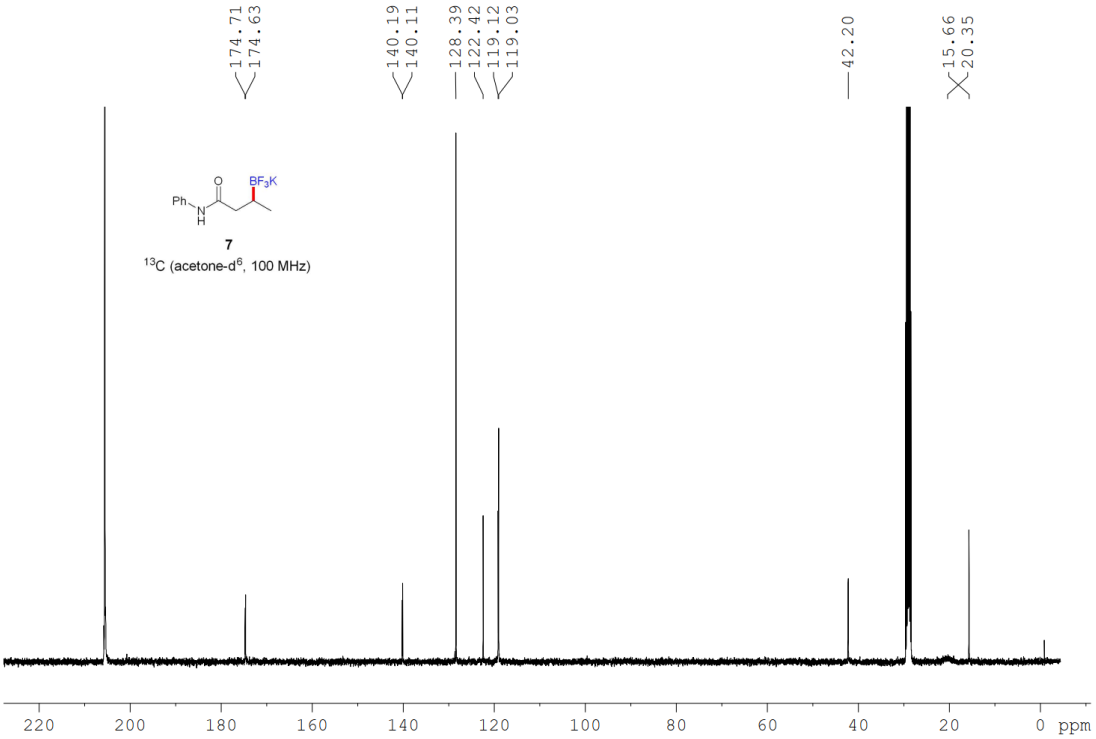
^{13}C NMR Spectra of **6**



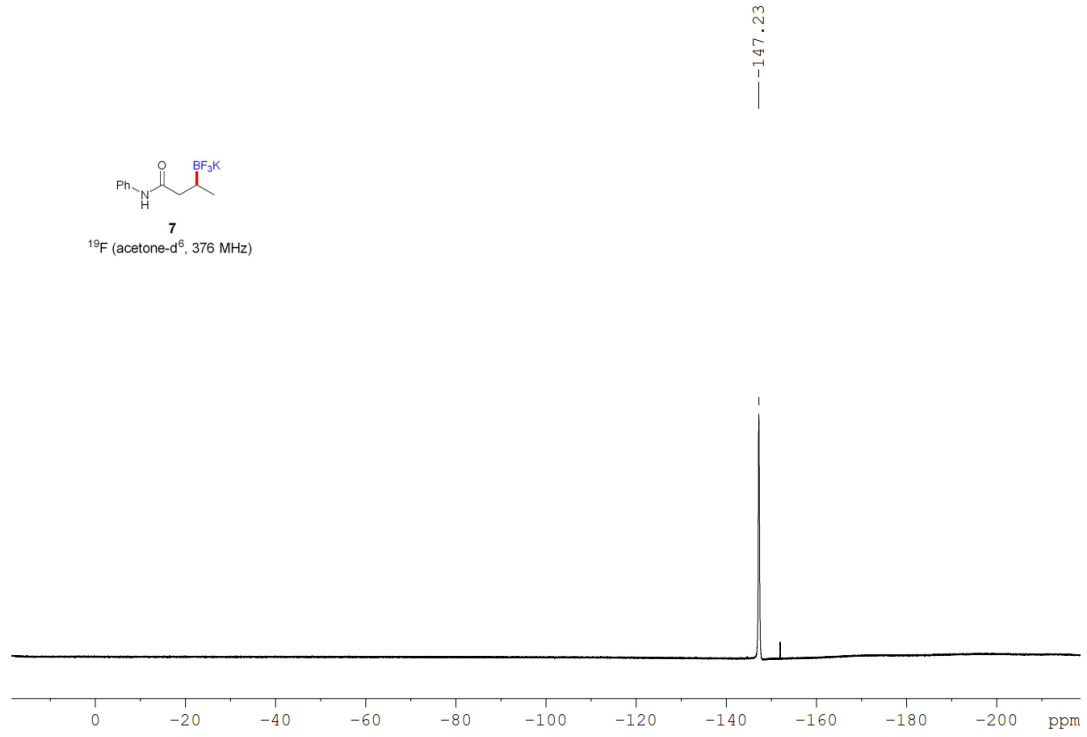
^{1}H NMR Spectra of **7**



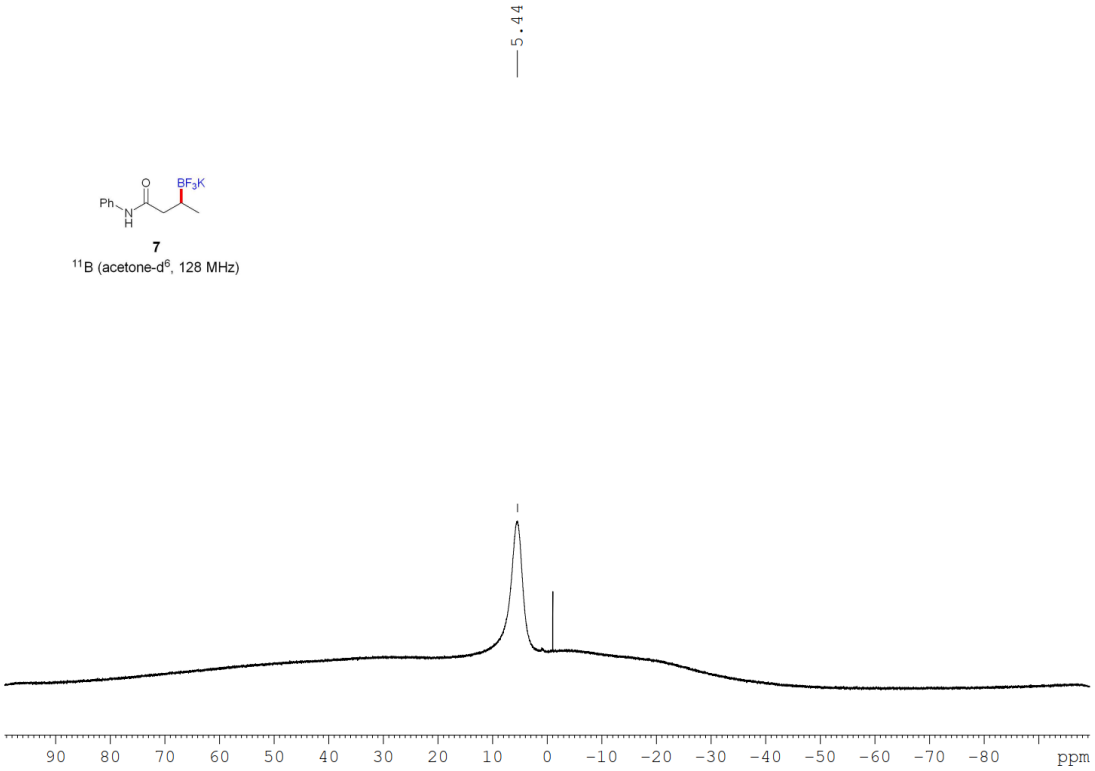
^{13}C NMR Spectra of **7**



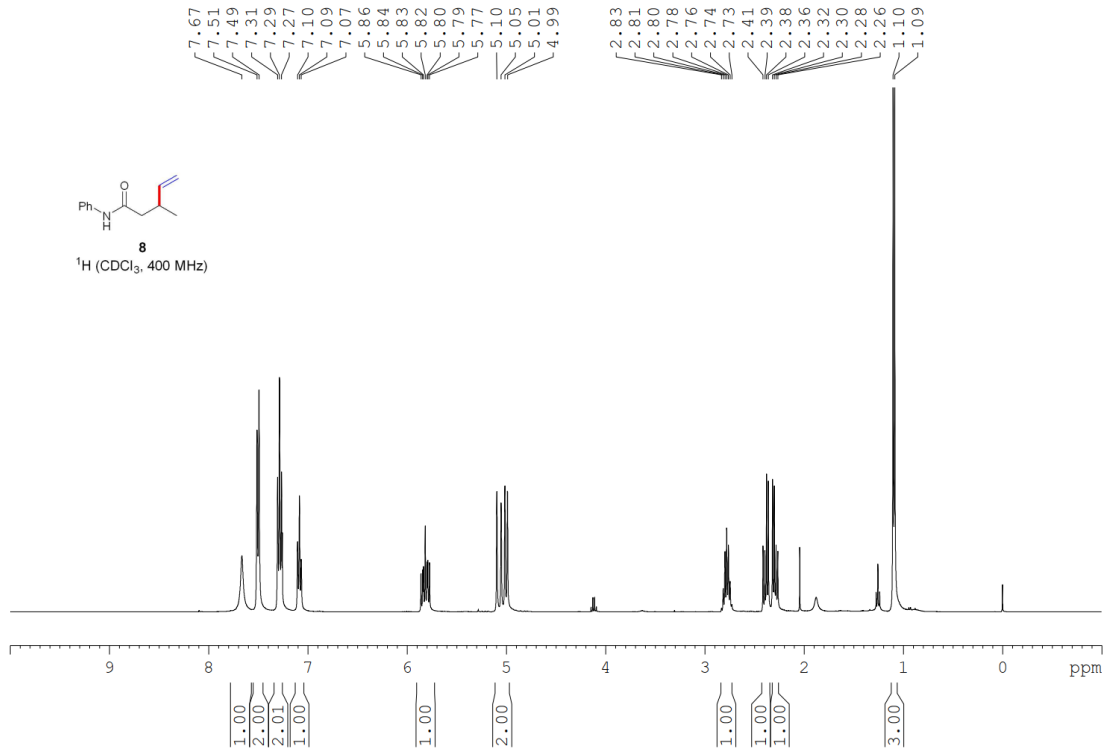
^{19}F NMR Spectra of **7**



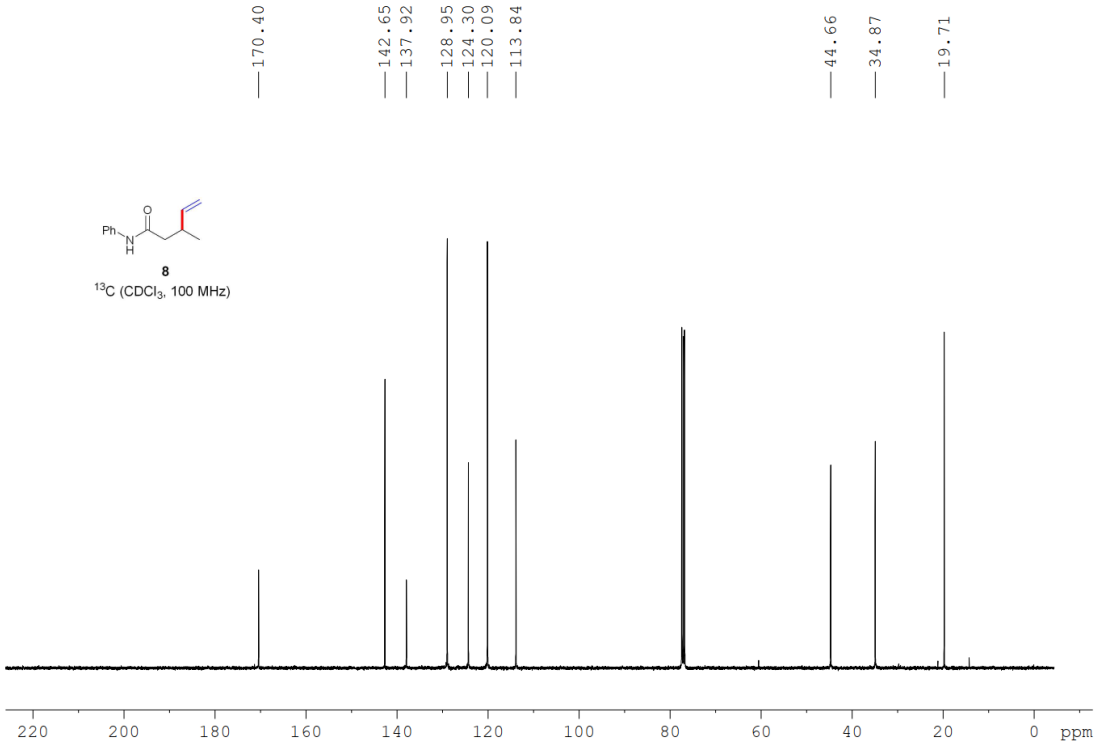
^{11}B NMR Spectra of **7**



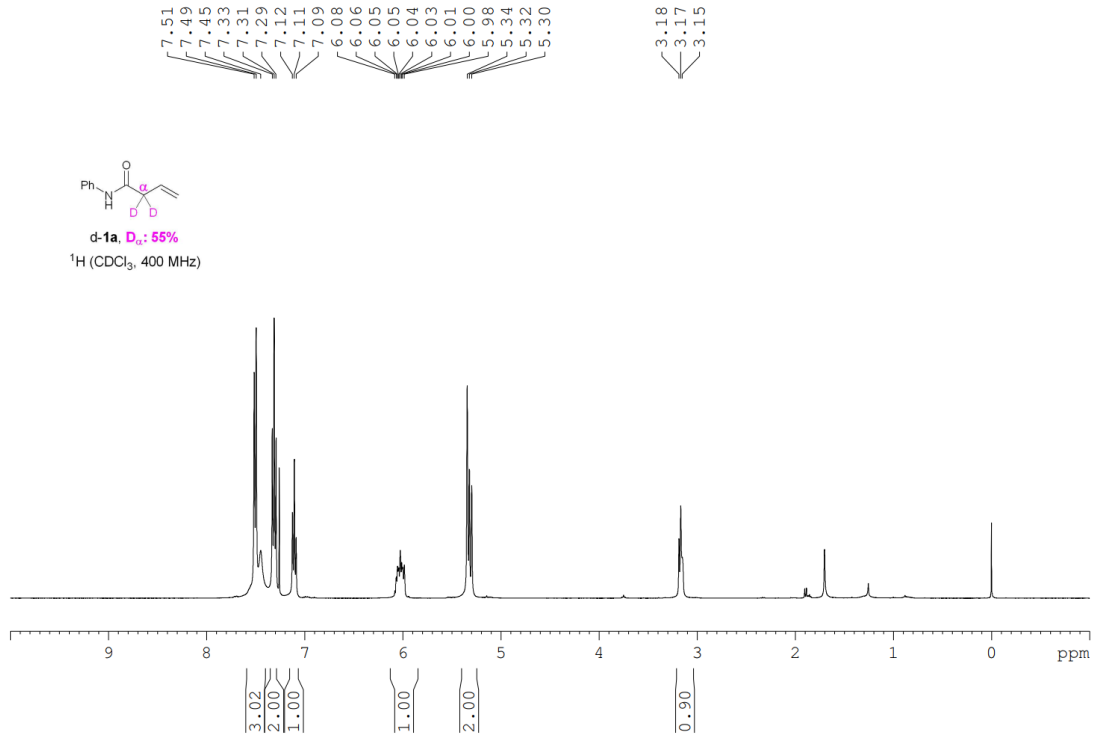
^{1}H NMR Spectra of **8**



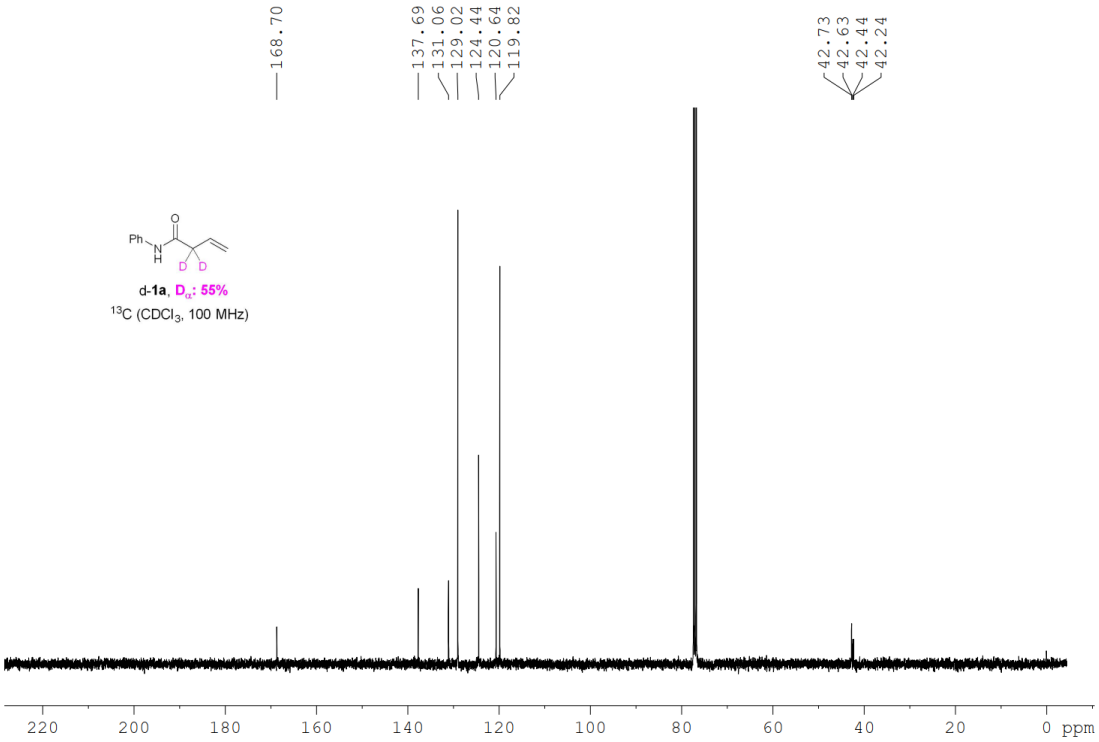
^{13}C NMR Spectra of **8**



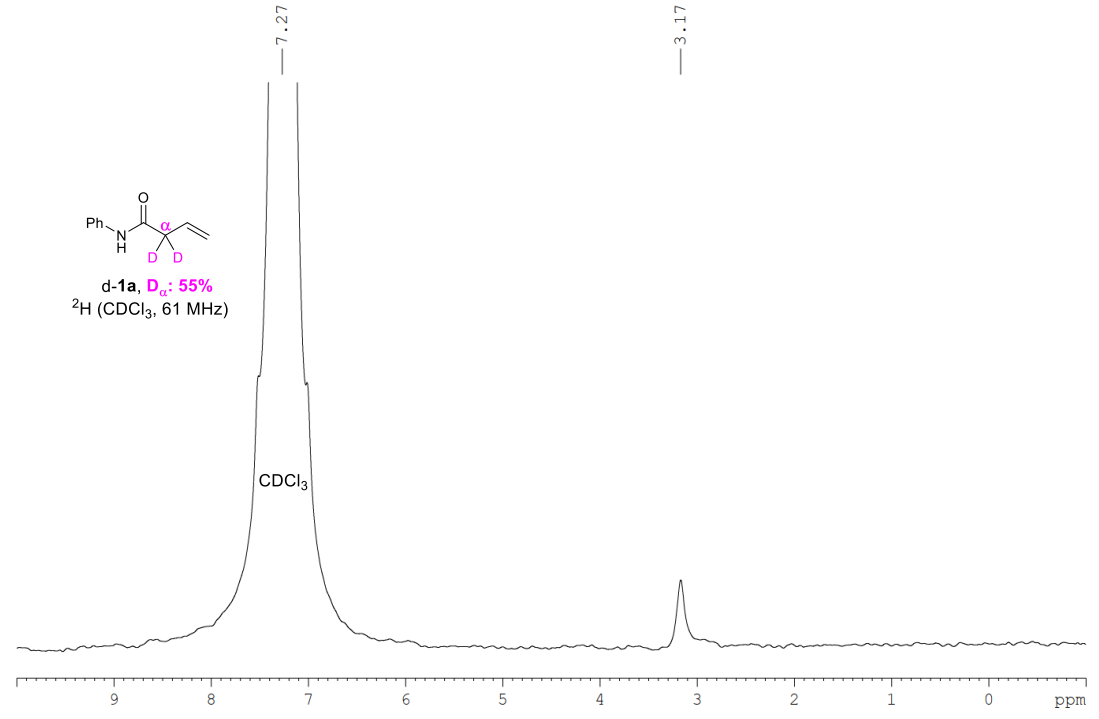
^{1}H NMR Spectra of d-**1a**



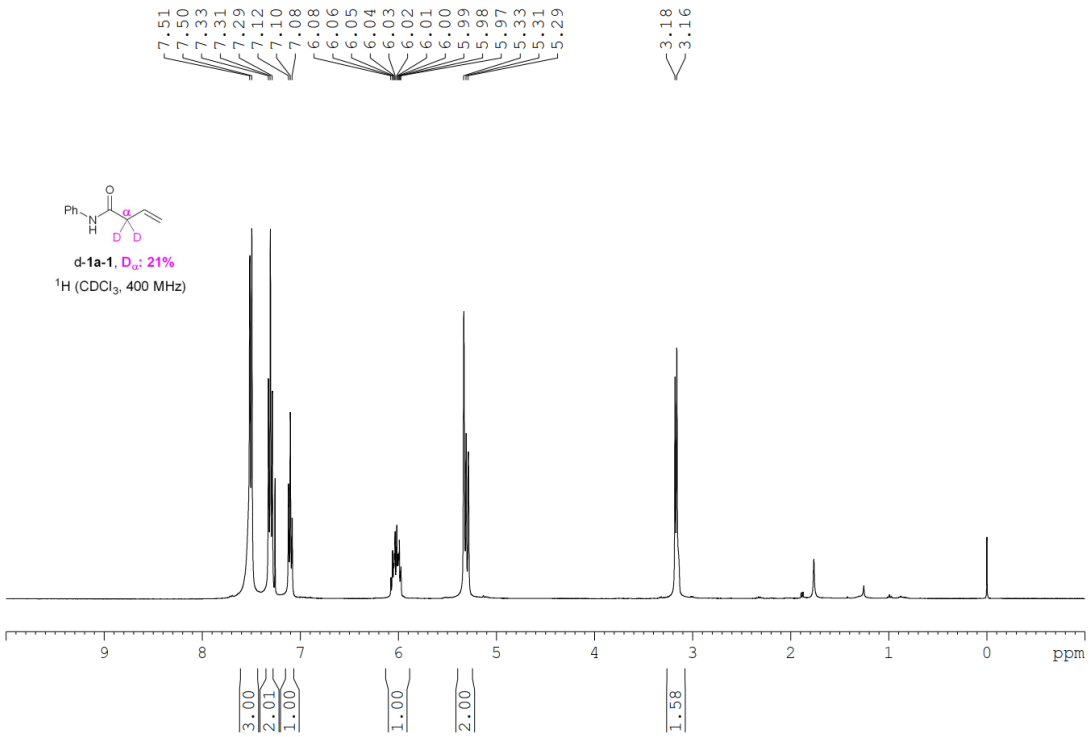
^{13}C NMR Spectra of d-**1a**



^{2}H NMR Spectra of d-**1a**



^{1}H NMR Spectra of d-**1a-1**



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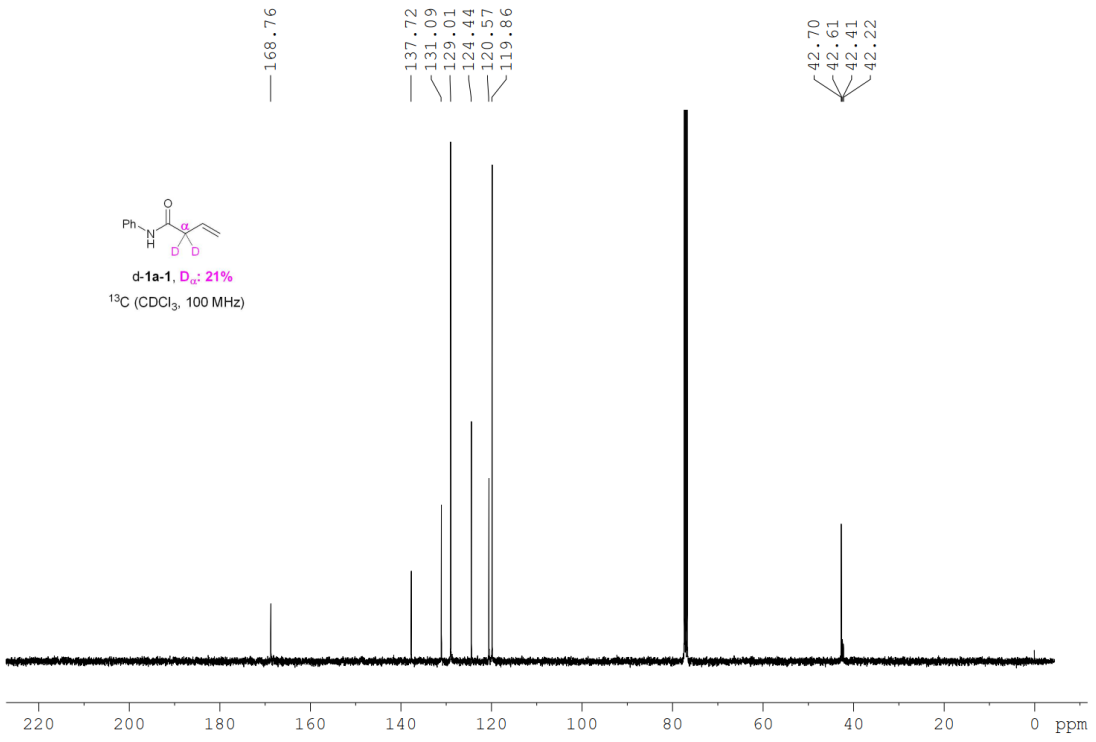

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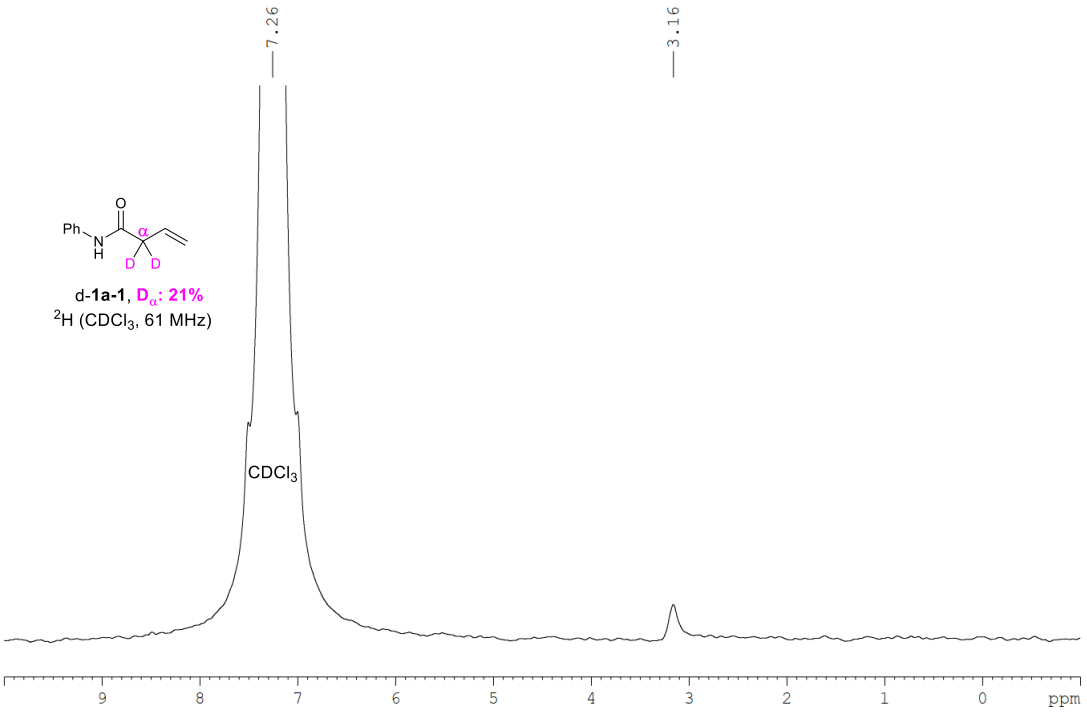
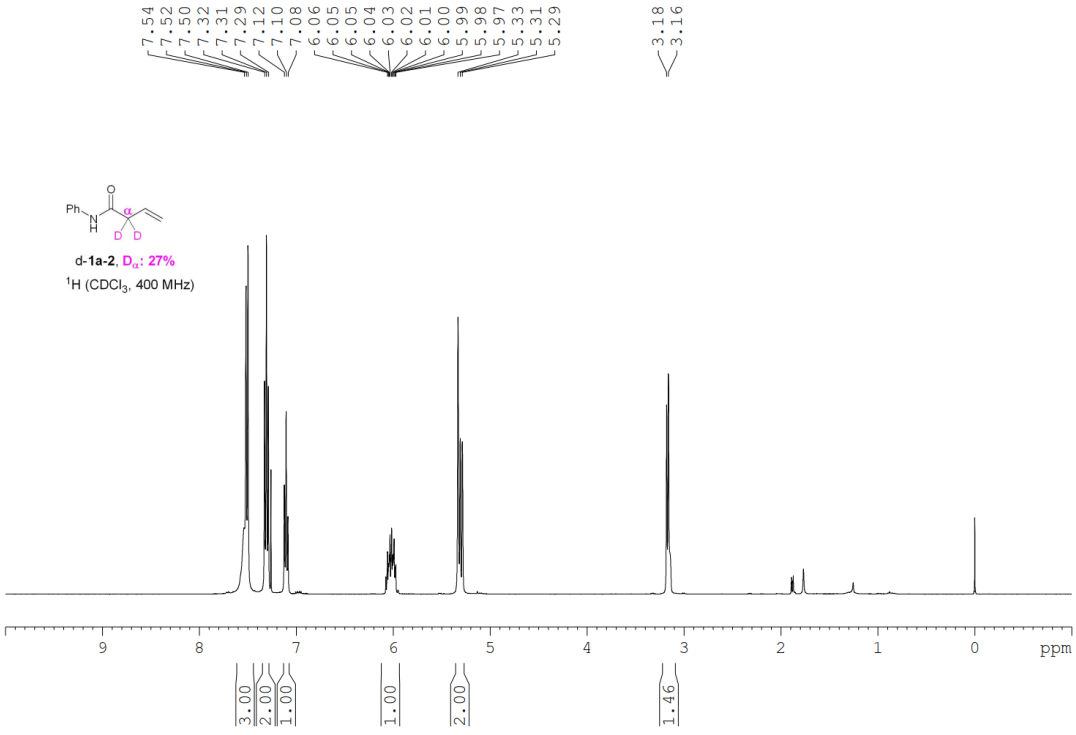
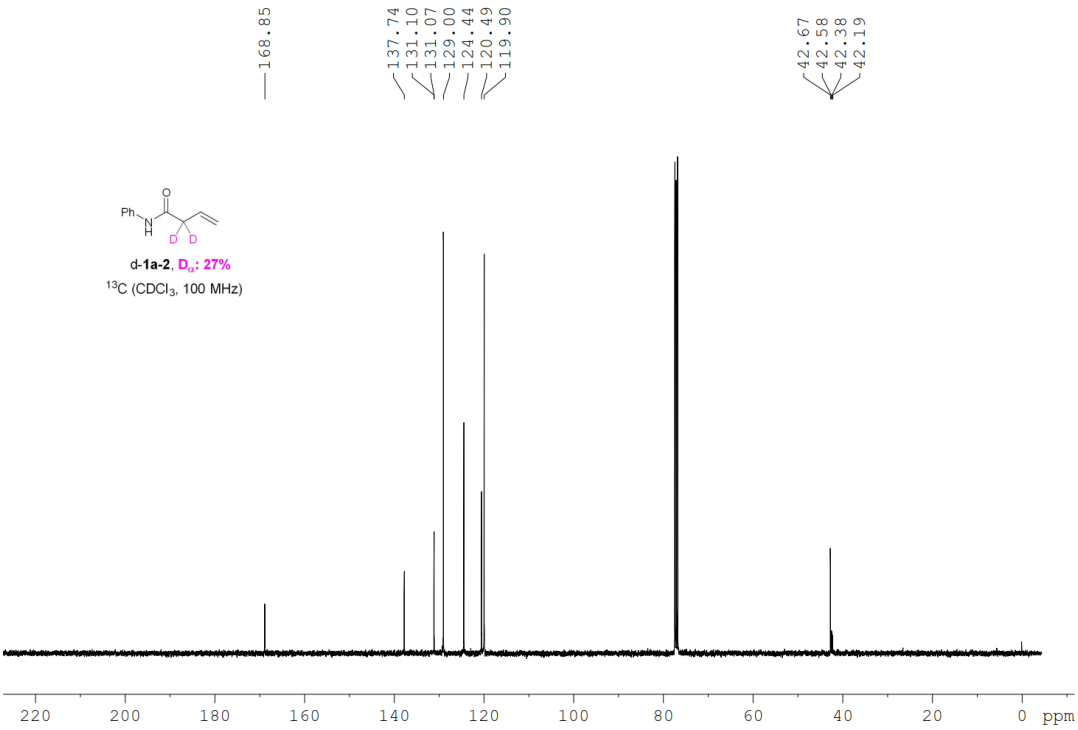


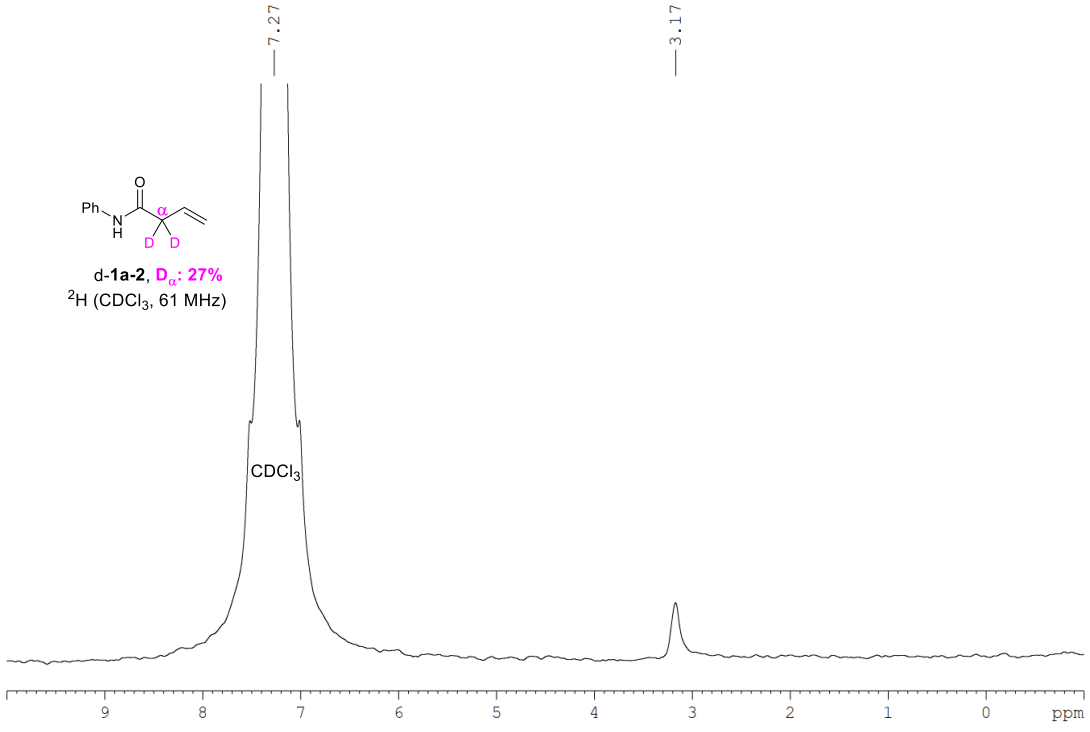
^{1}H NMR Spectra of d-**1a-2**



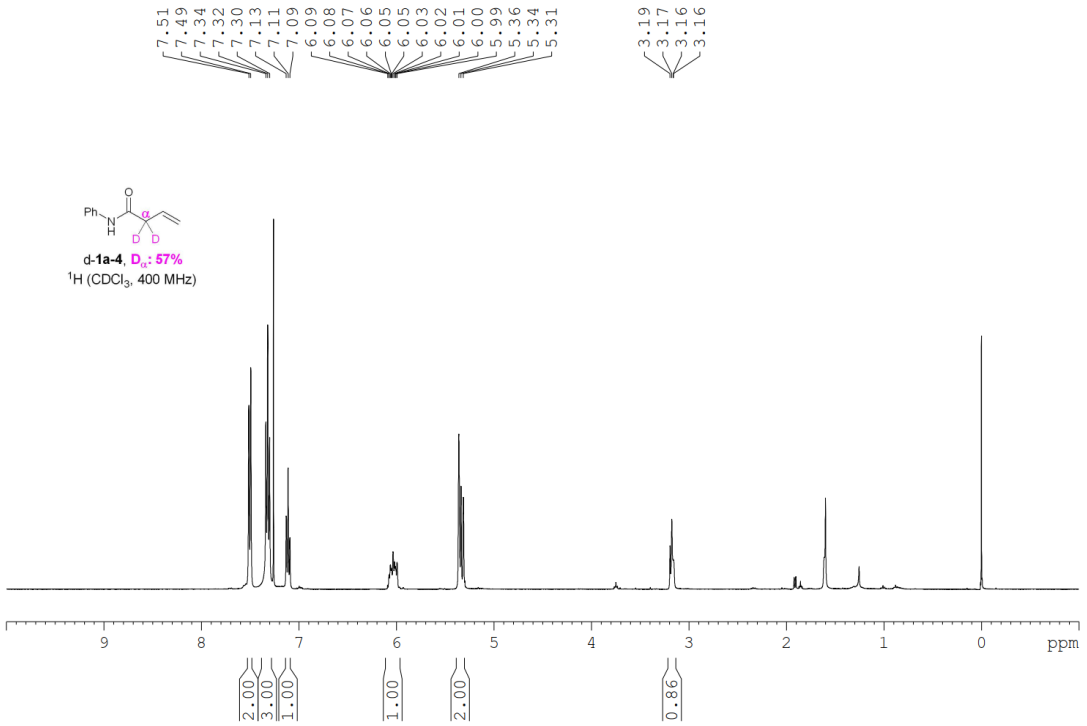
^{13}C NMR Spectra of d-**1a-2**



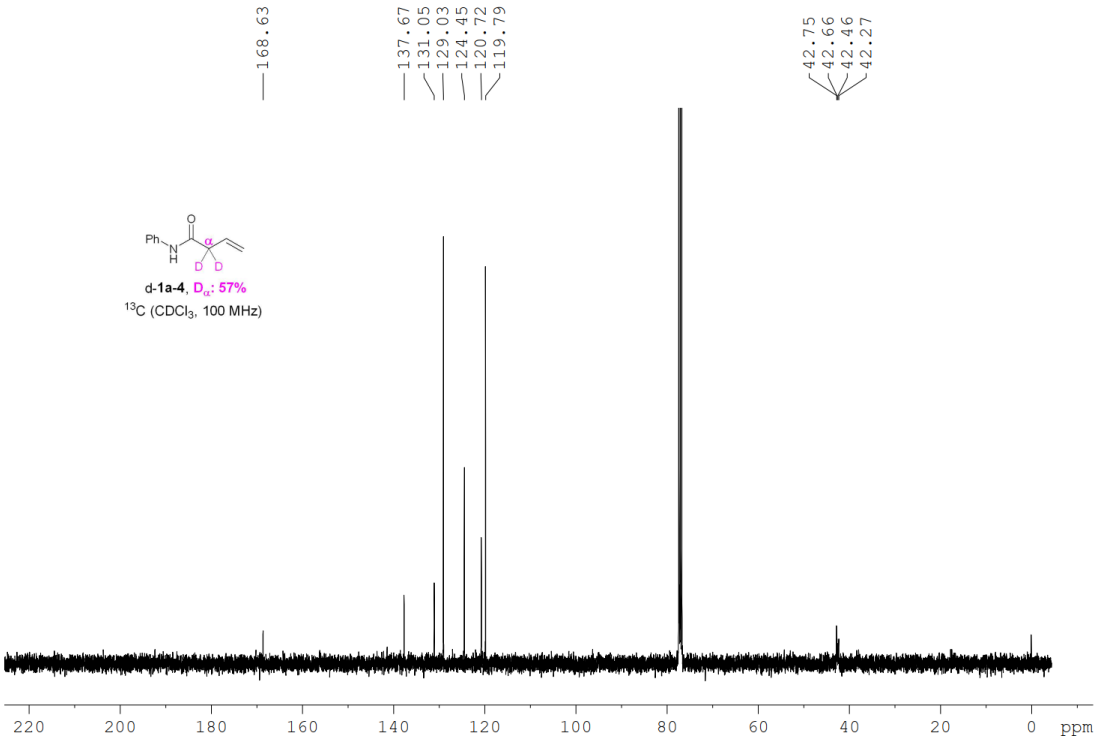
^{2}H NMR Spectra of d-**1a-2**



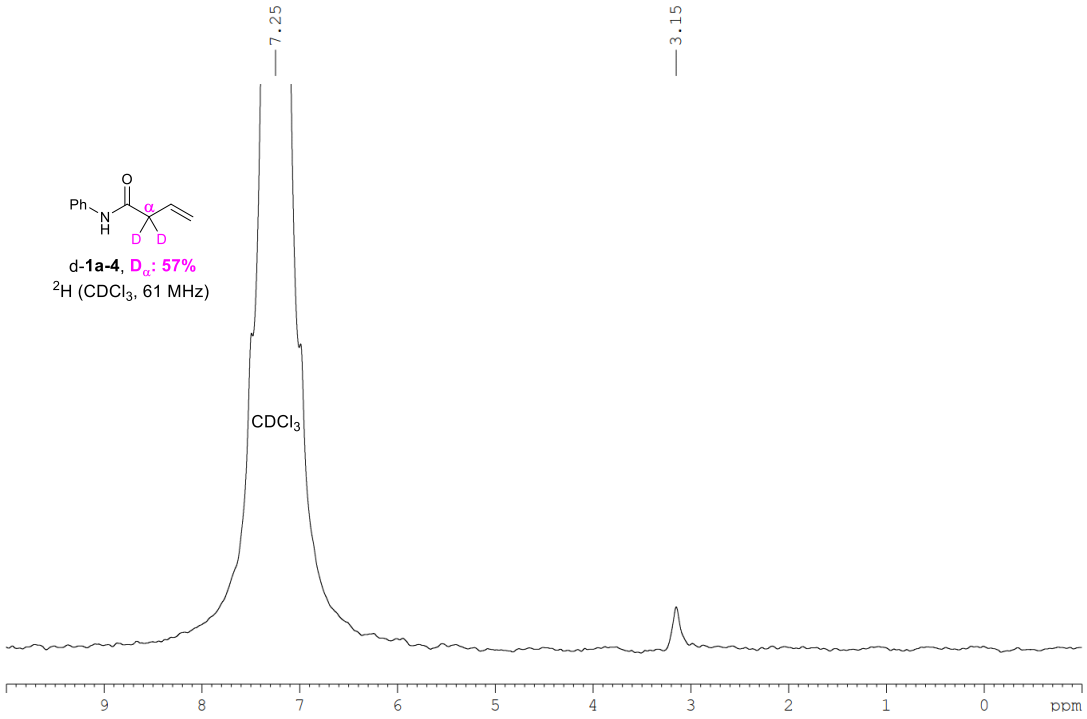
^{1}H NMR Spectra of d-**1a-4**



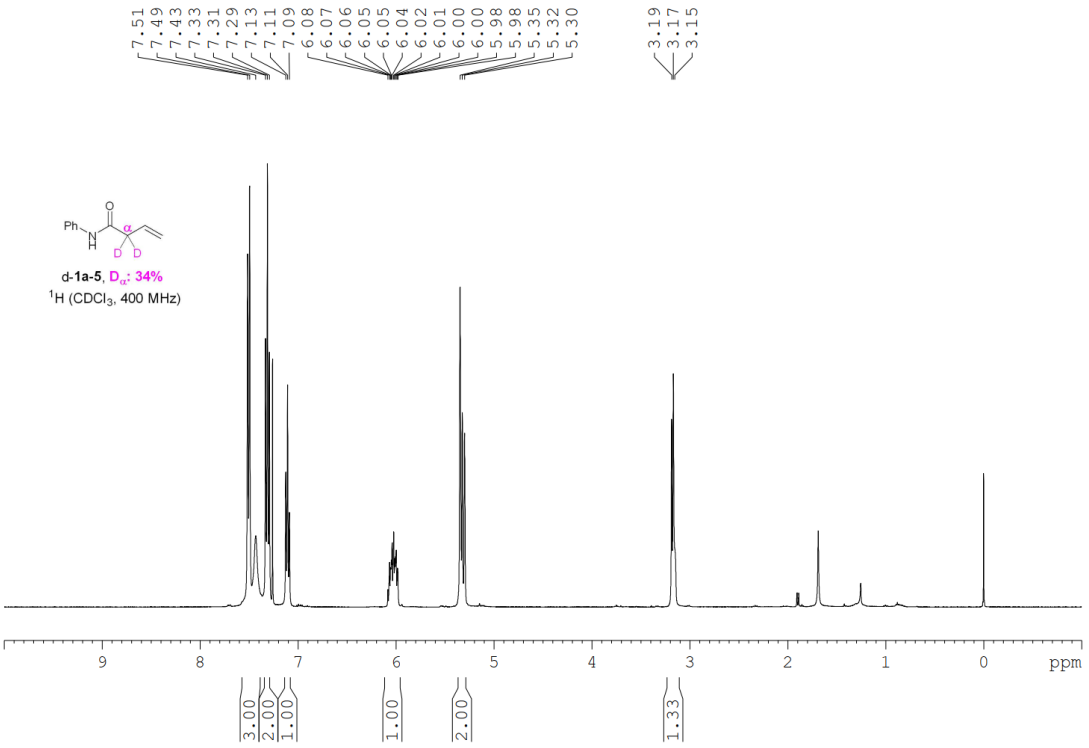
^{13}C NMR Spectra of d-**1a-4**



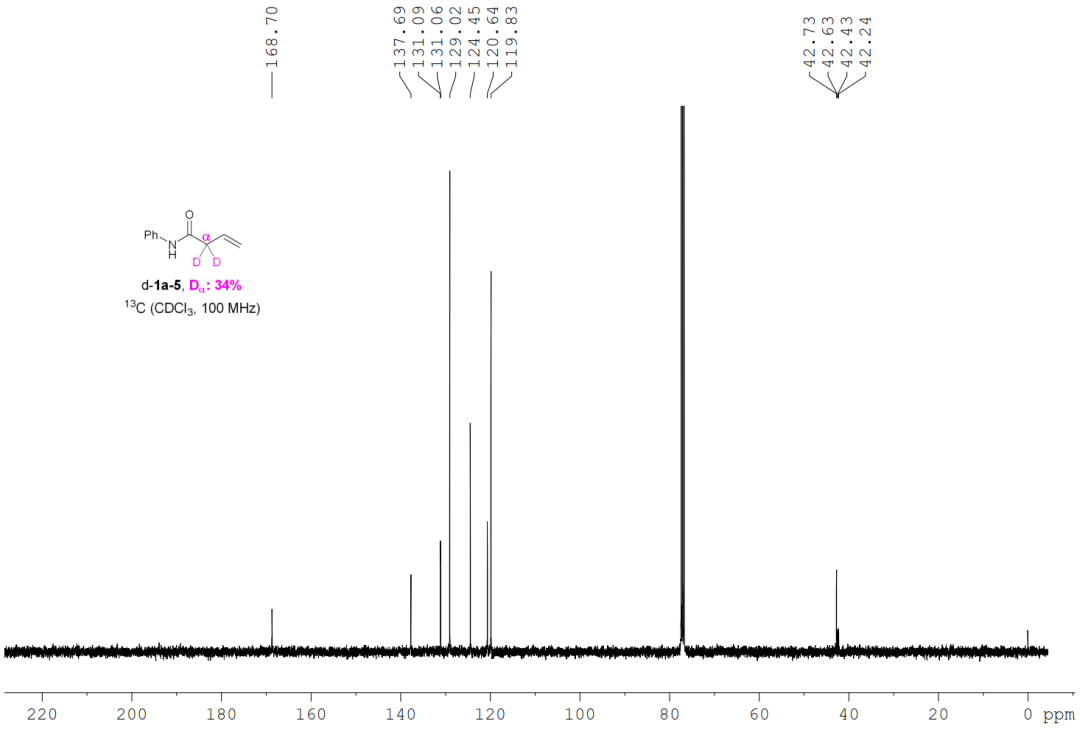
^{2}H NMR Spectra of d-**1a-4**



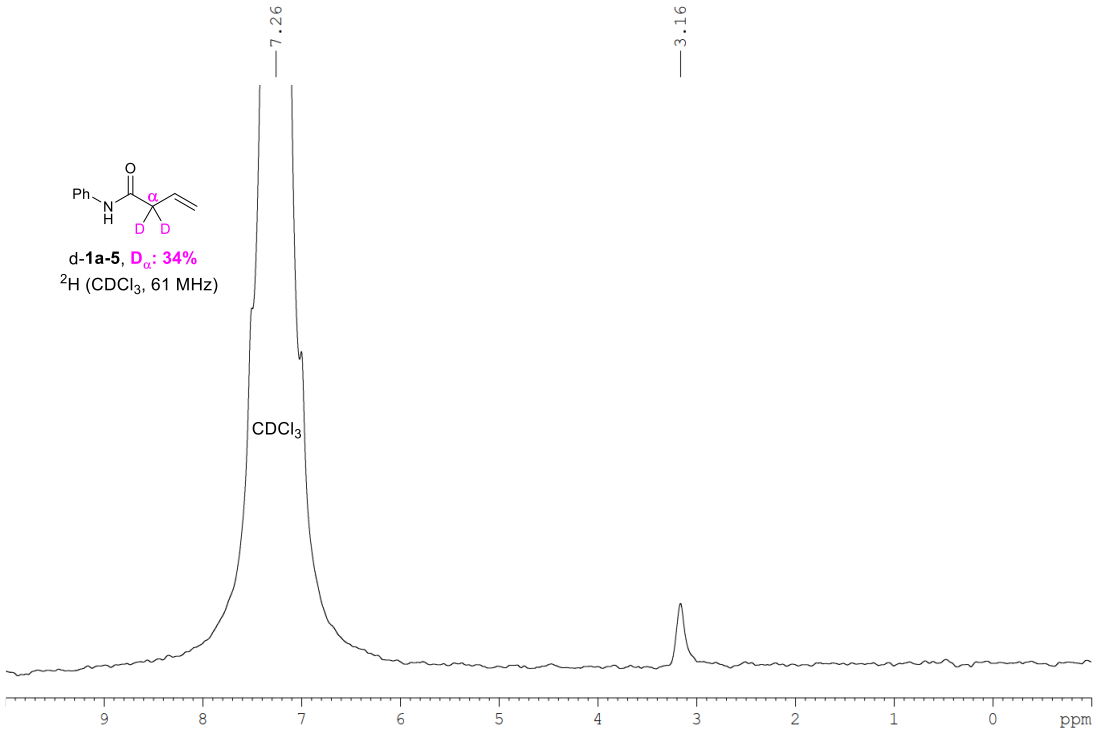
^{1}H NMR Spectra of d-**1a-5**



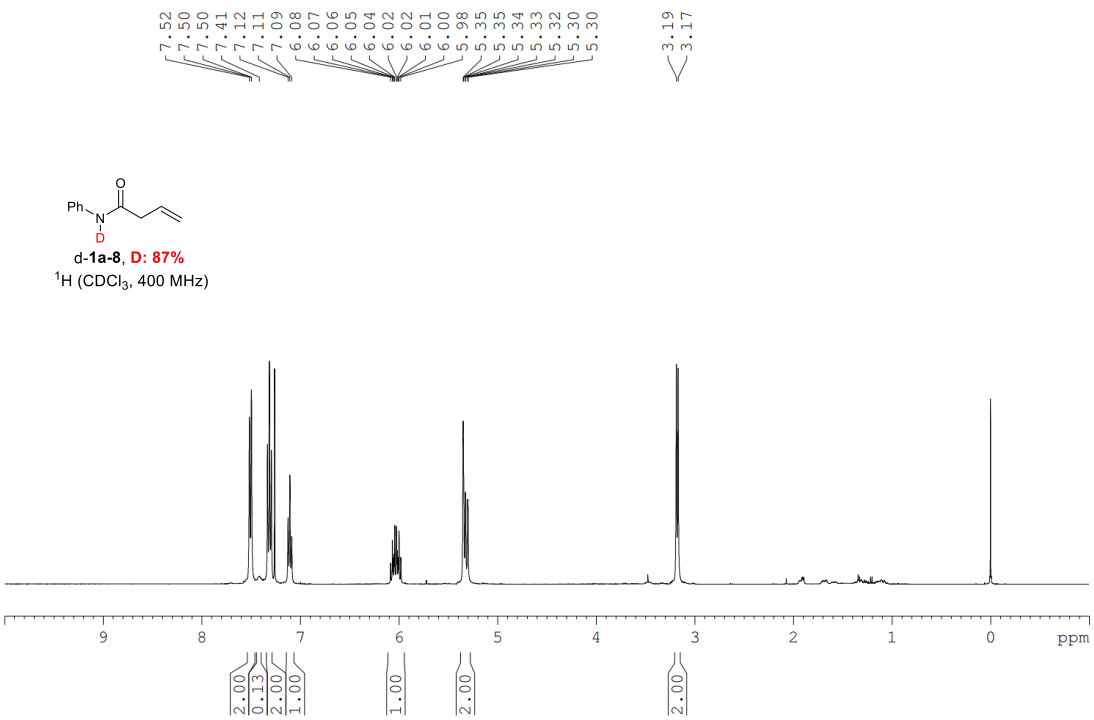
^{13}C NMR Spectra of d-**1a-5**



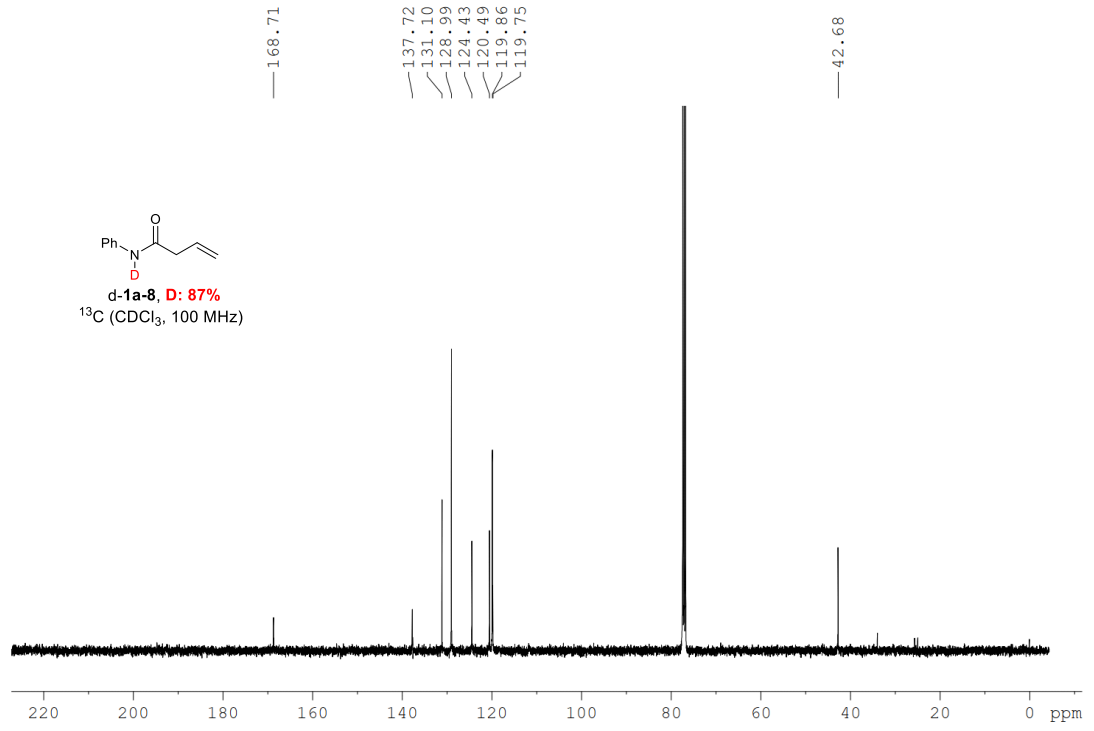
^{2}H NMR Spectra of d-**1a-5**



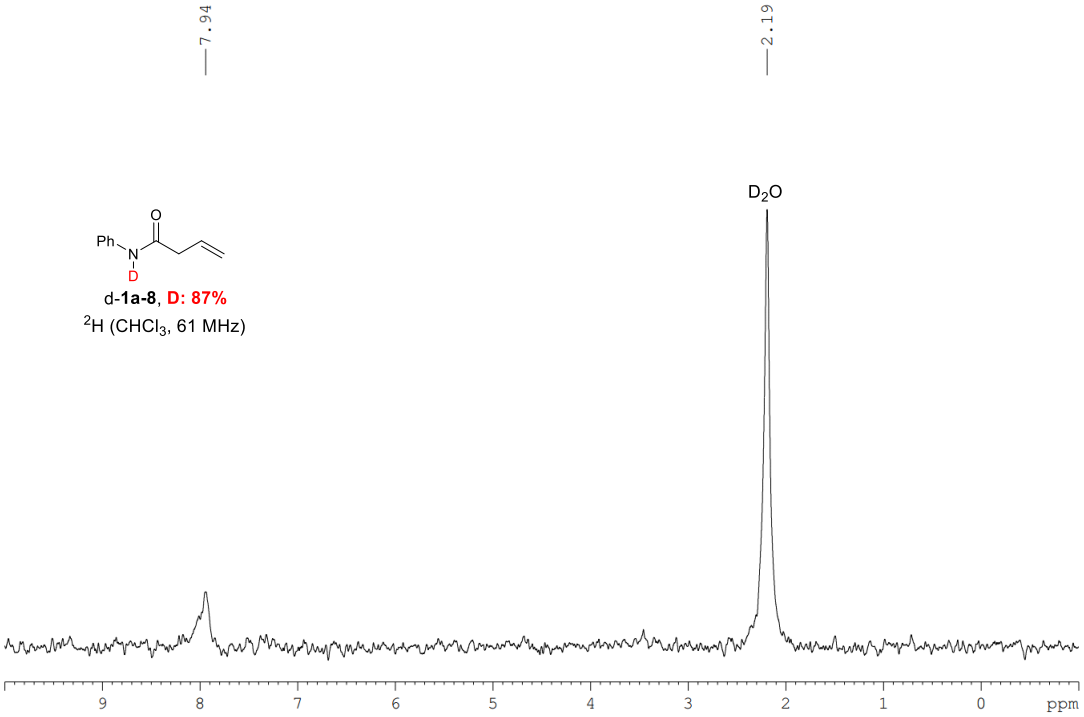
^{1}H NMR Spectra of d-**1a-8**



^{13}C NMR Spectra of d-**1a-8**



^{2}H NMR Spectra of d-**1a-8**

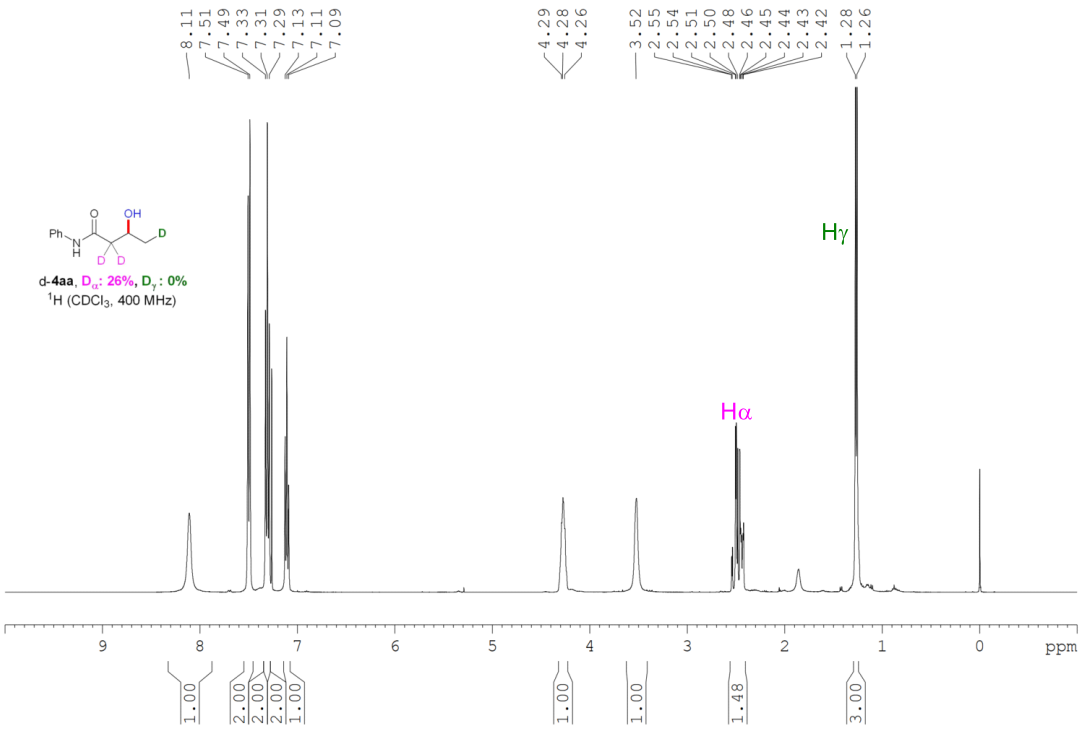


d-**1a-8**, **D: 87%**

^{2}H ($CHCl_3$, 61 MHz)

* D_2O was generated by H/D exchange reaction of H_2O in $CHCl_3$ with d-**1a-8**.

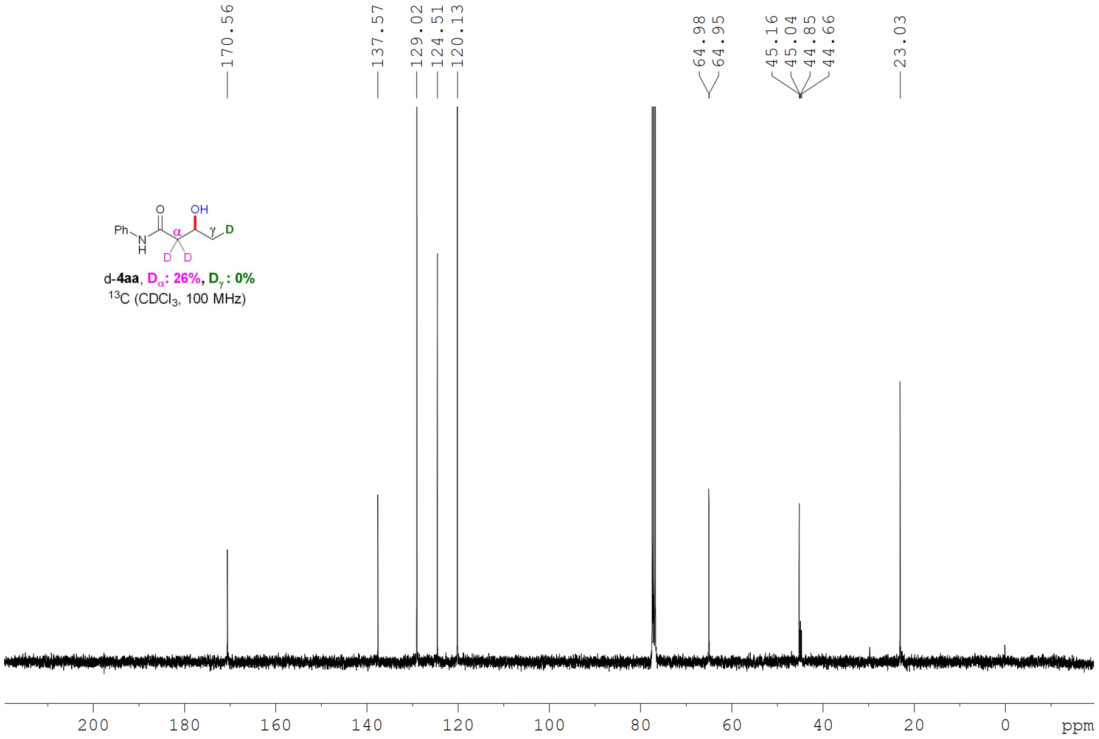
^{1}H NMR Spectra of d-**4aa**



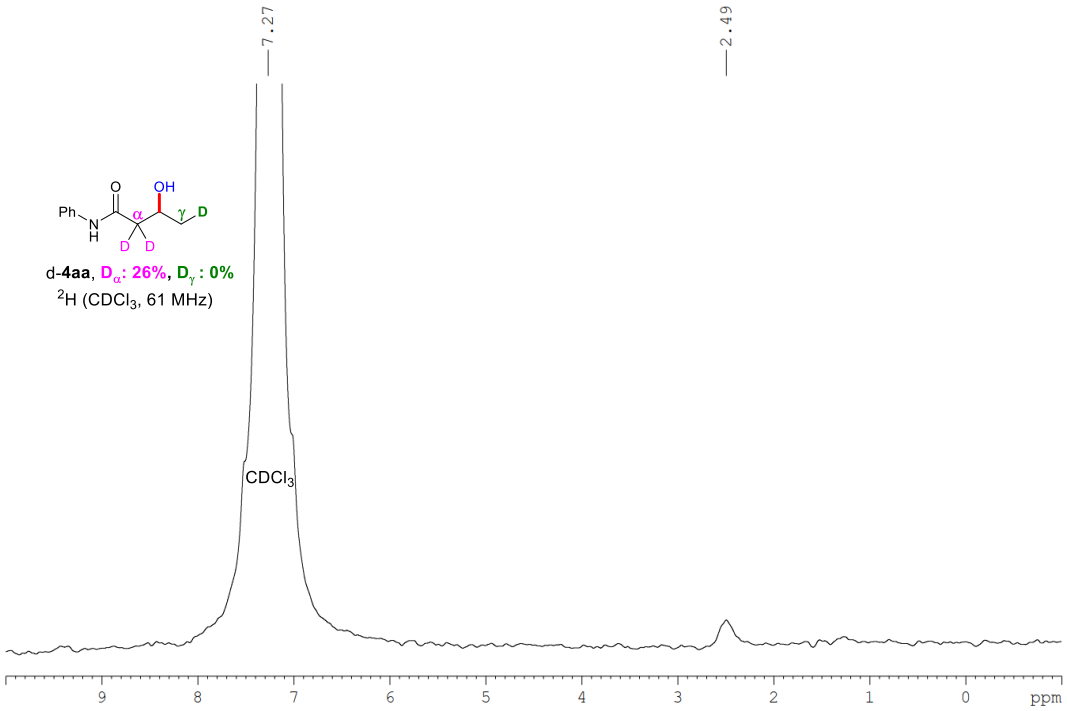
d-**4aa**, D_α: **26%**, D_γ: **0%**

^{1}H ($CDCl_3$, 400 MHz)

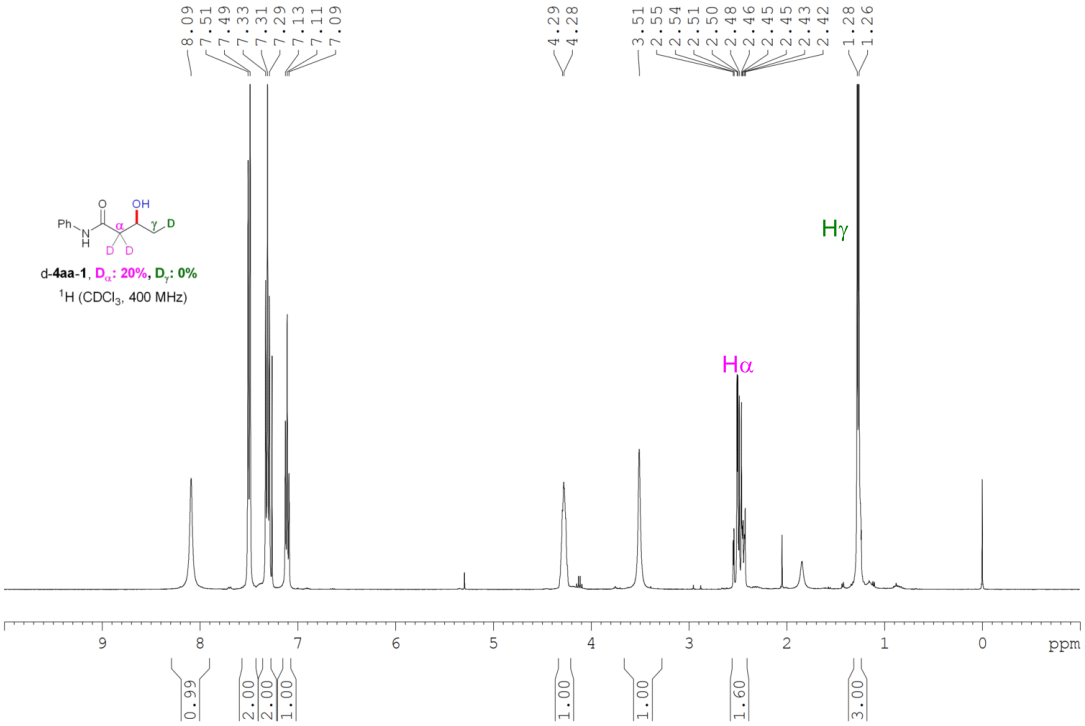
^{13}C NMR Spectra of d-**4aa**



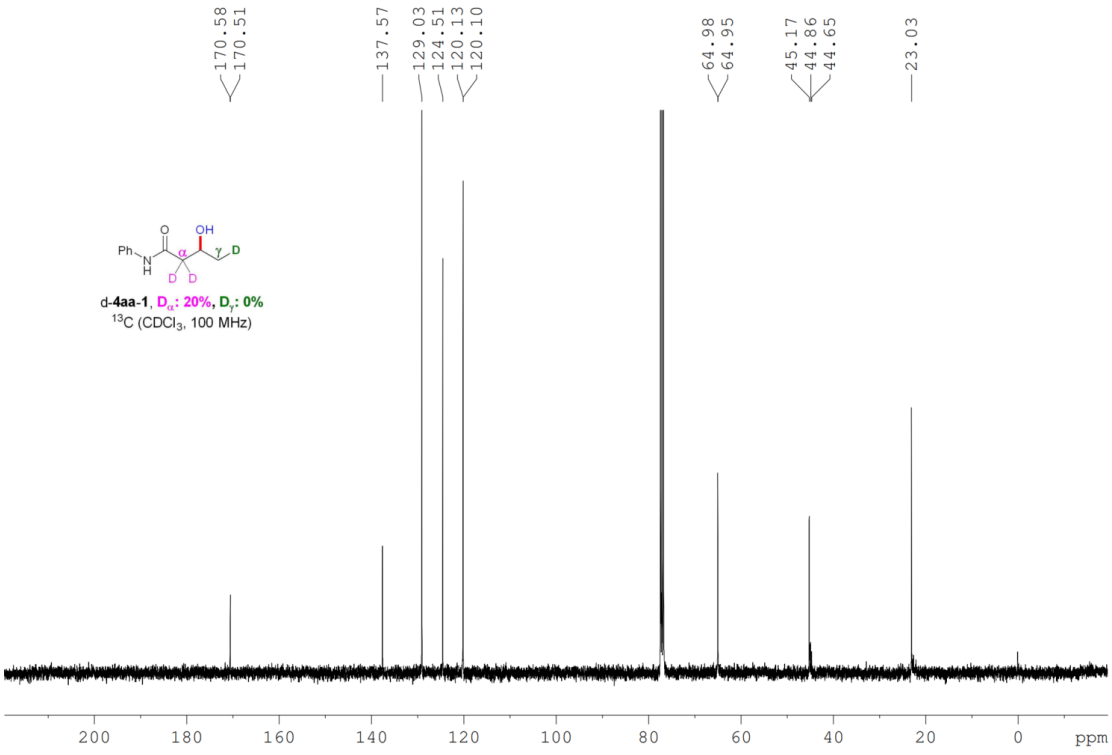
^{2}H NMR Spectra of d-**4aa**



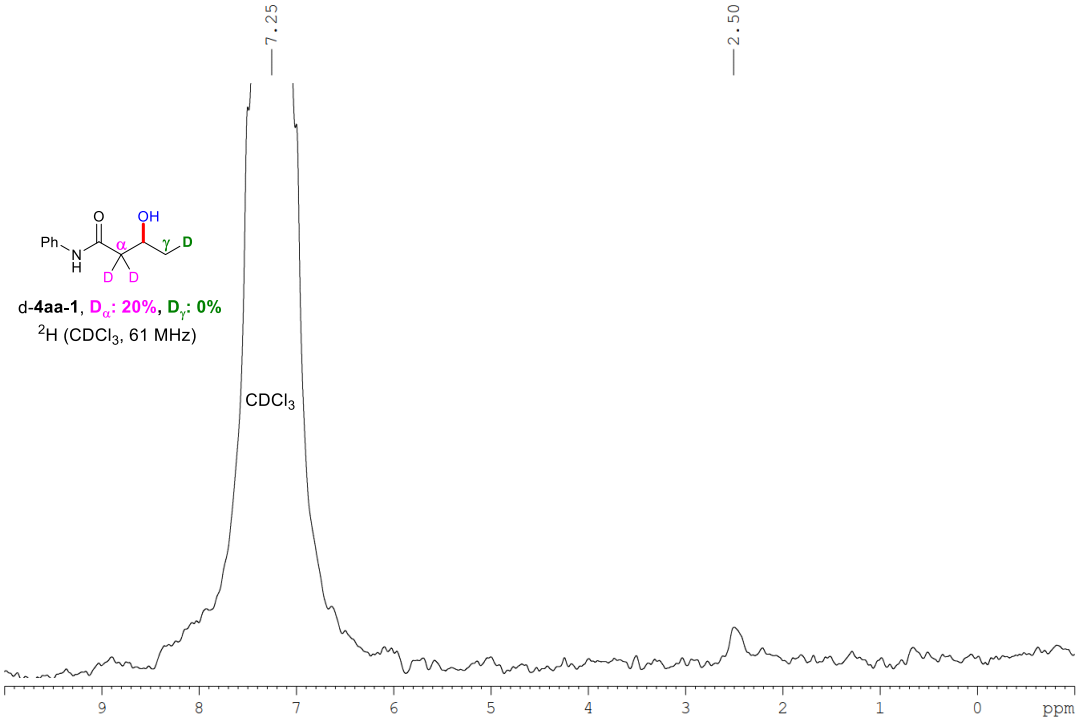
^{1}H NMR Spectra of d-**4aa-1**



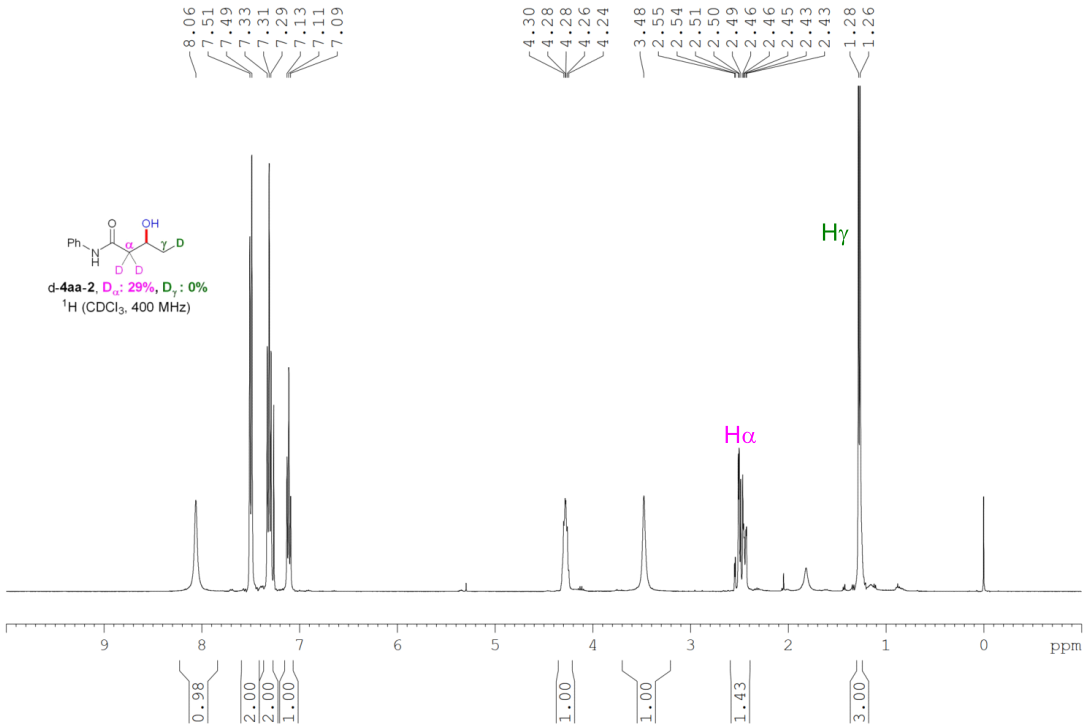
^{13}C NMR Spectra of d-**4aa-1**



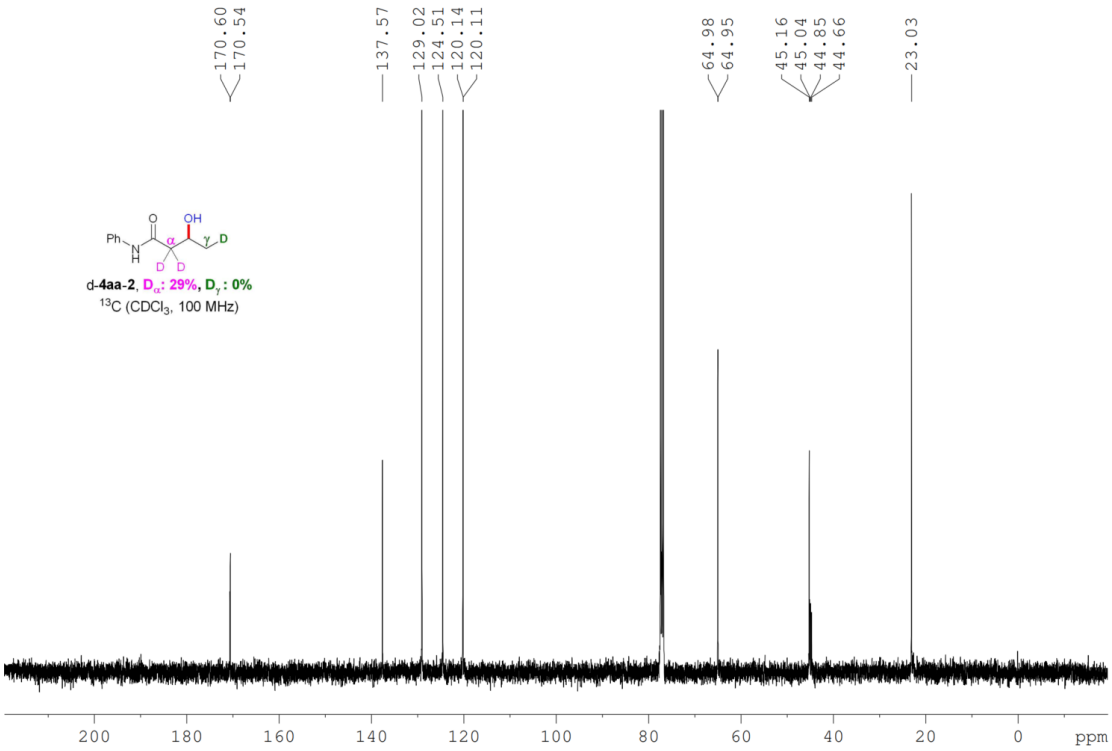
^{2}H NMR Spectra of d-**4aa-1**



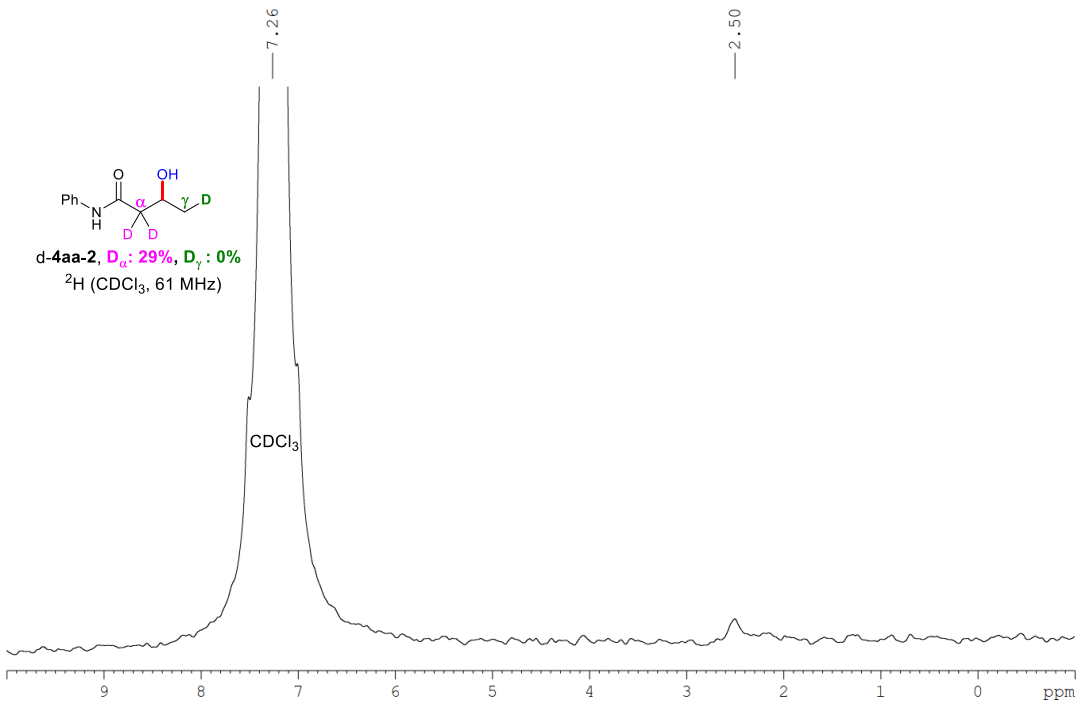
^{1}H NMR Spectra of d-**4aa-2**



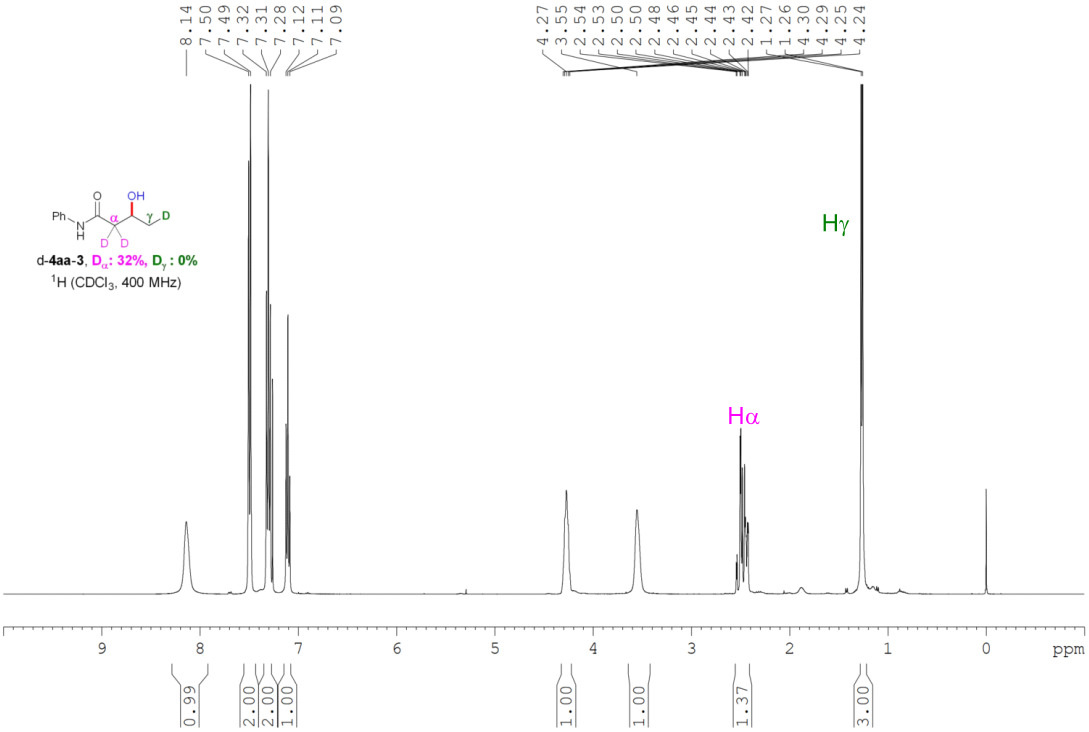
^{13}C NMR Spectra of d-**4aa-2**



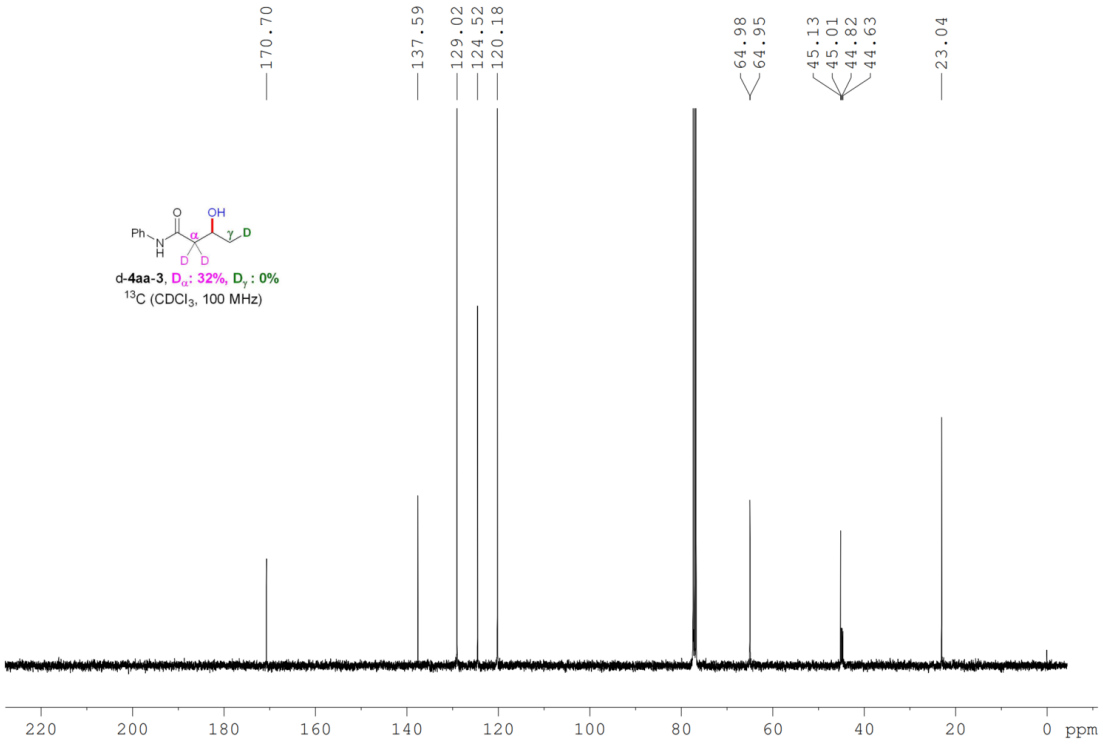
^{2}H NMR Spectra of d-**4aa-2**



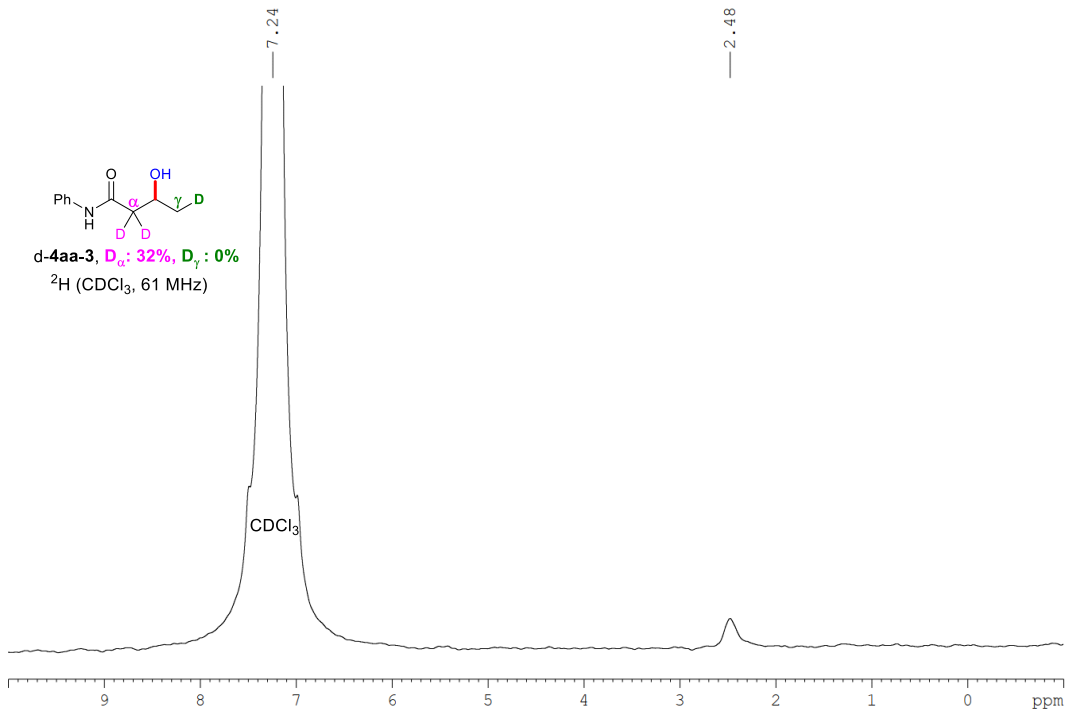
^{1}H NMR Spectra of d-**4aa-3**



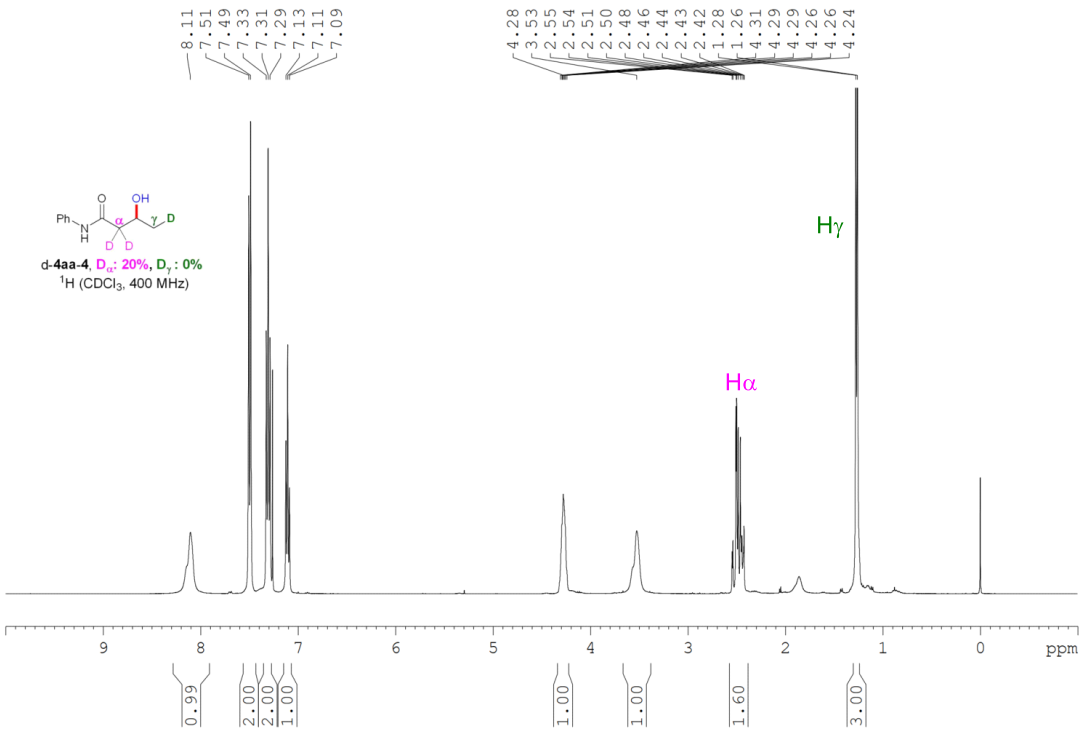
^{13}C NMR Spectra of d-**4aa-3**



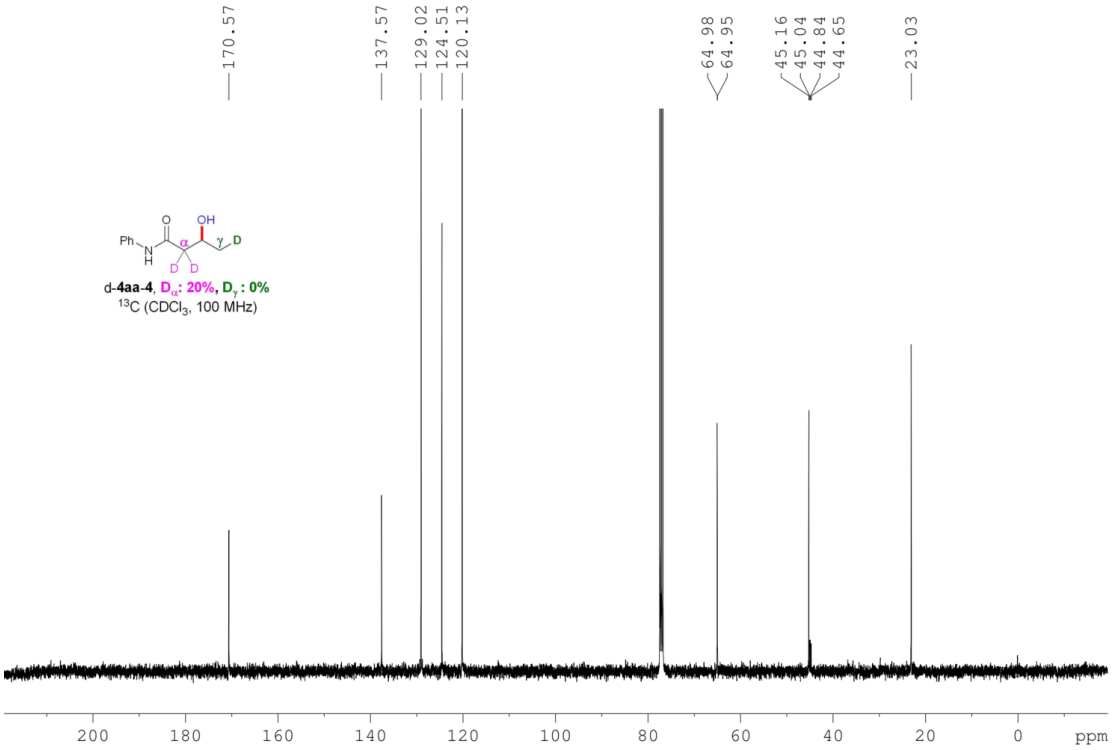
^{2}H NMR Spectra of d-**4aa-3**



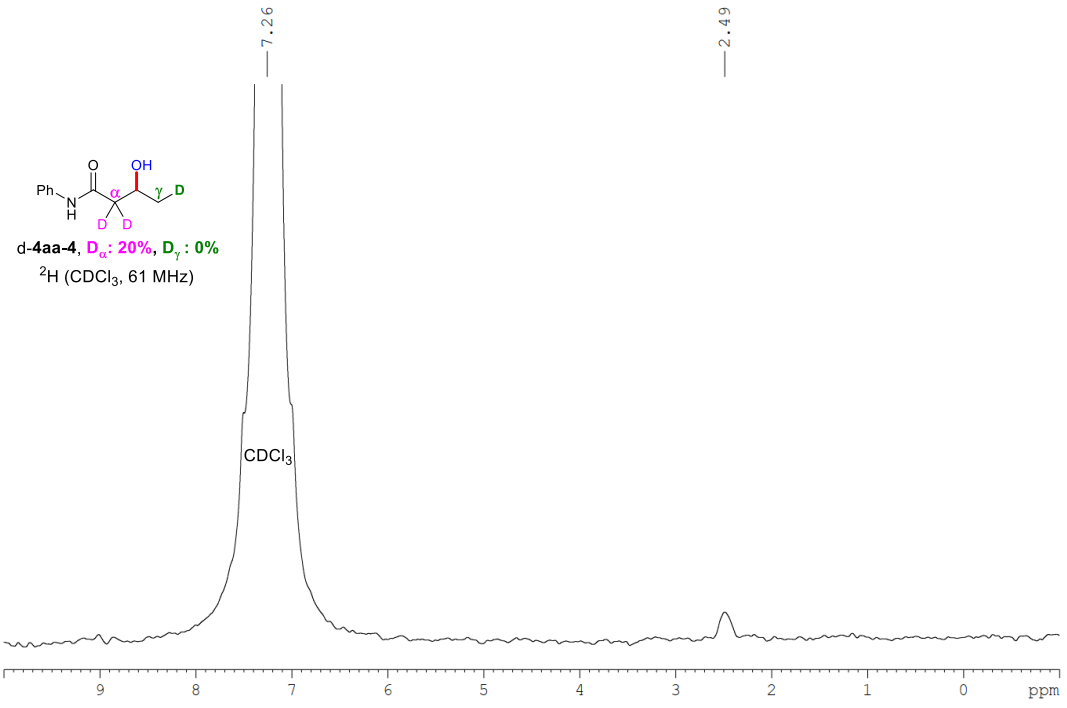
^{1}H NMR Spectra of d-**4aa-4**



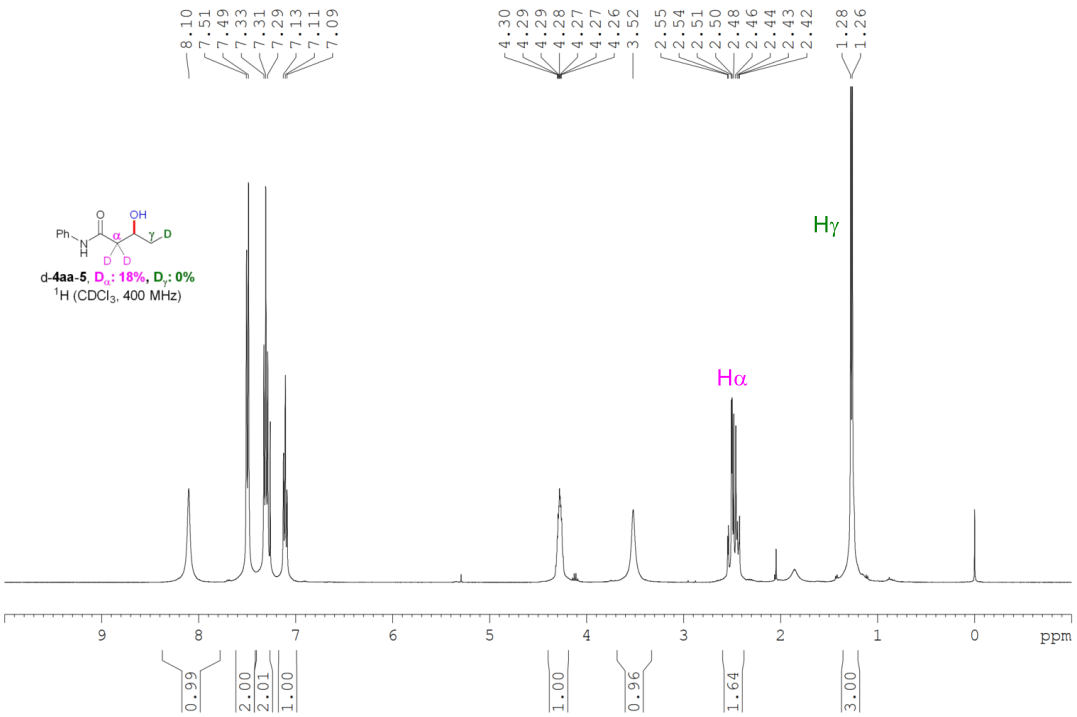
^{13}C NMR Spectra of d-**4aa-4**



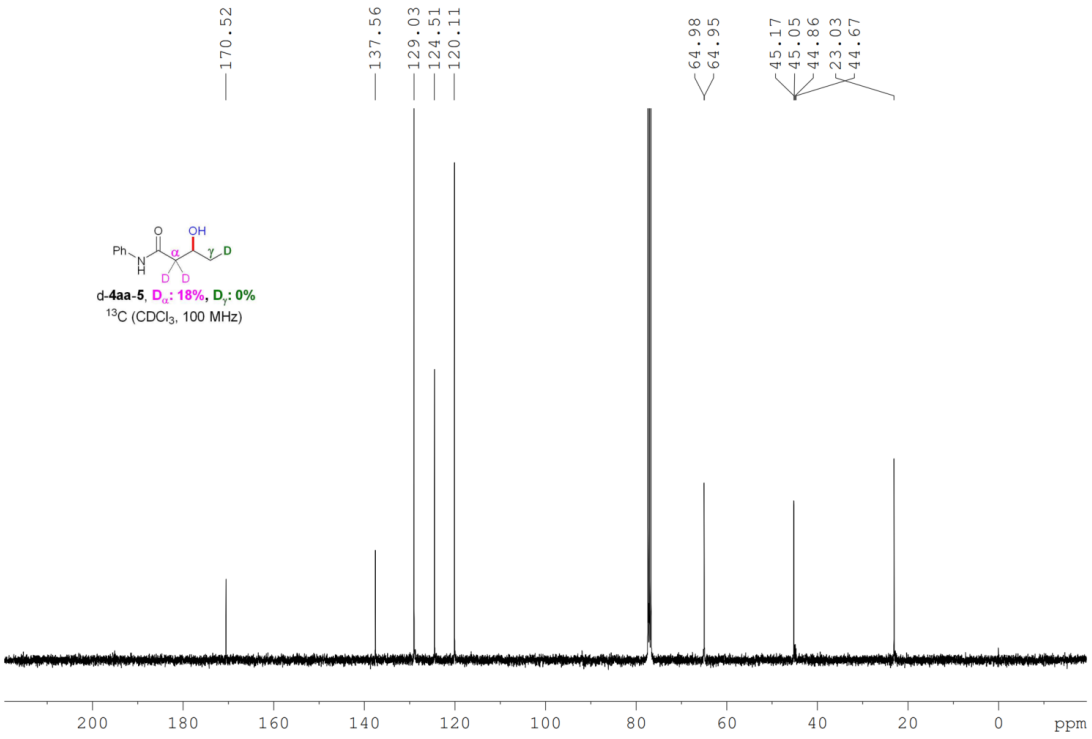
^{2}H NMR Spectra of d-**4aa-4**



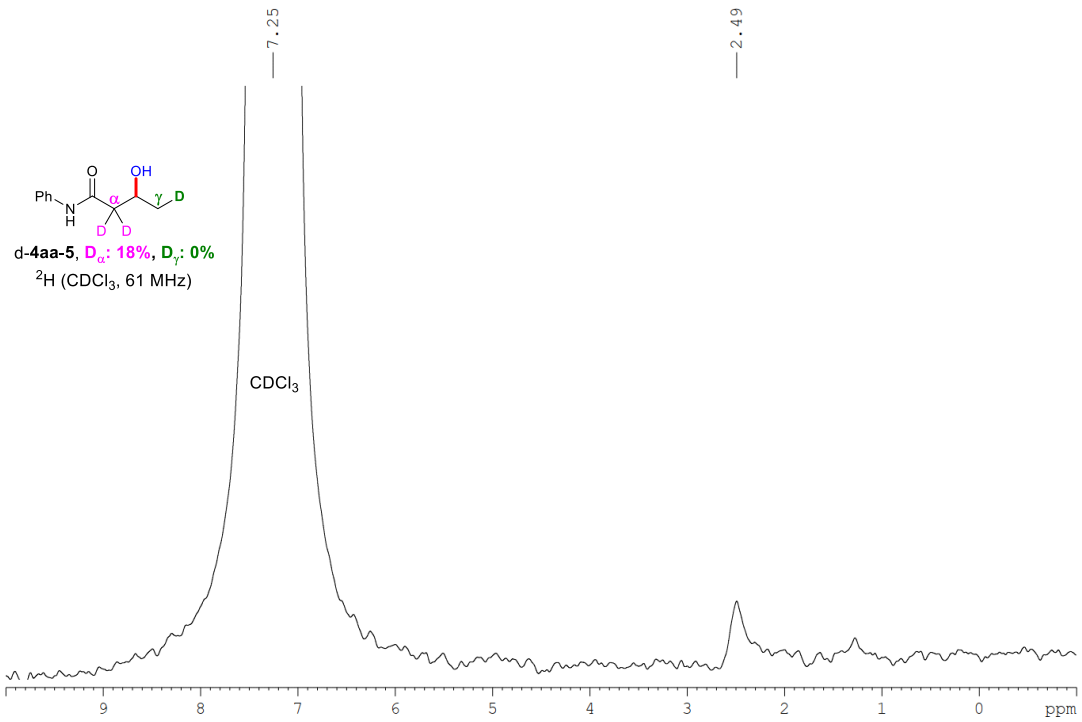
^{1}H NMR Spectra of d-**4aa-5**



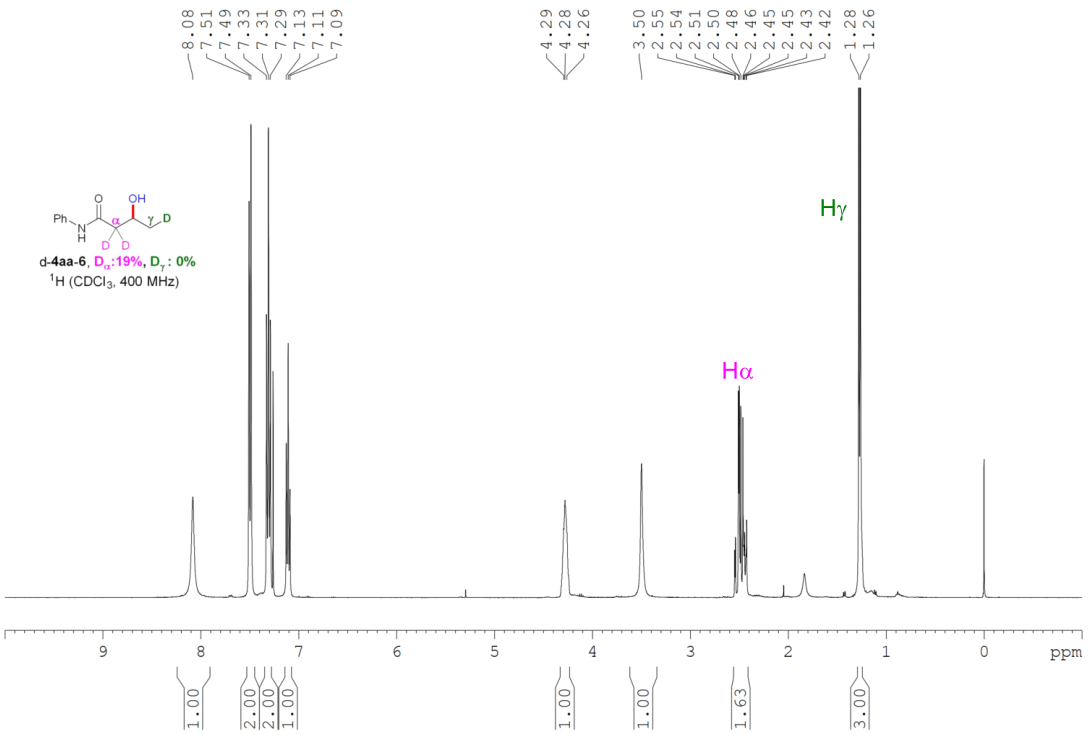
^{13}C NMR Spectra of d-**4aa-5**



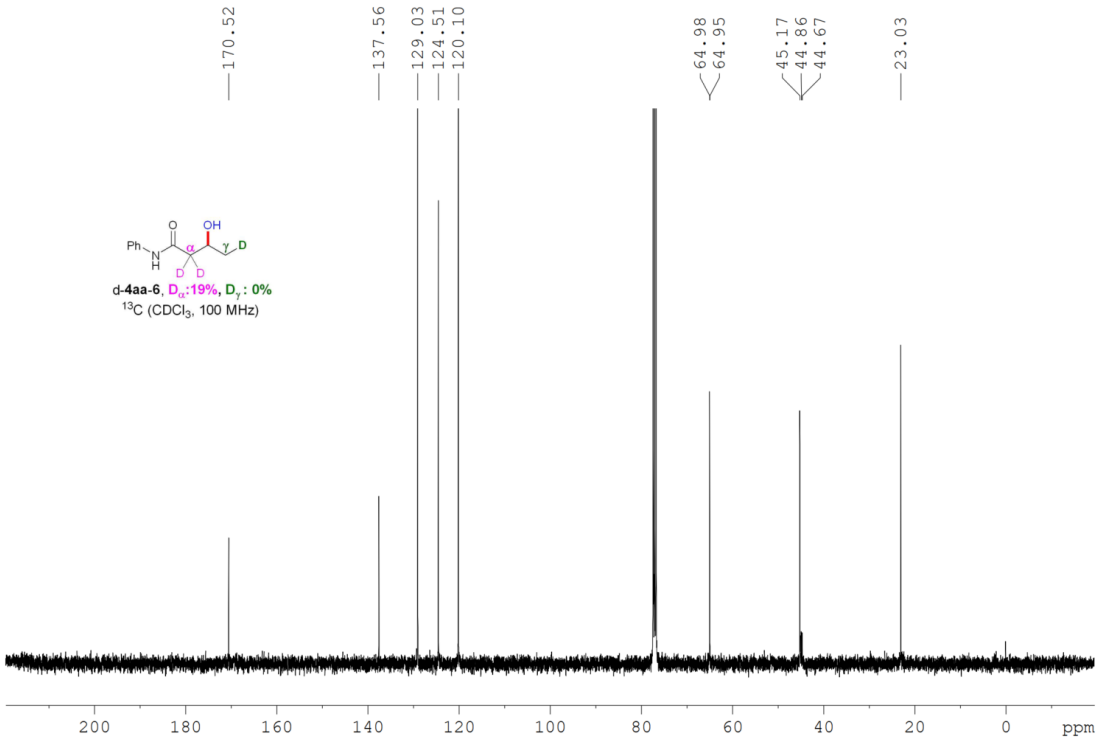
^{2}H NMR Spectra of d-**4aa-5**



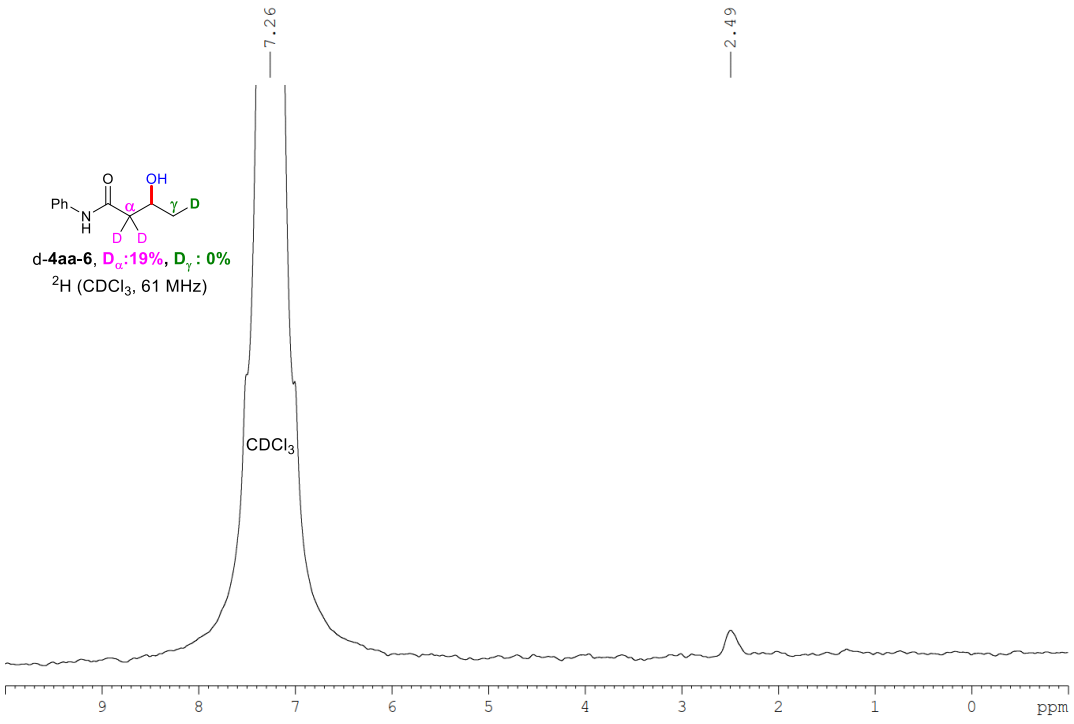
^{1}H NMR Spectra of d-**4aa-6**



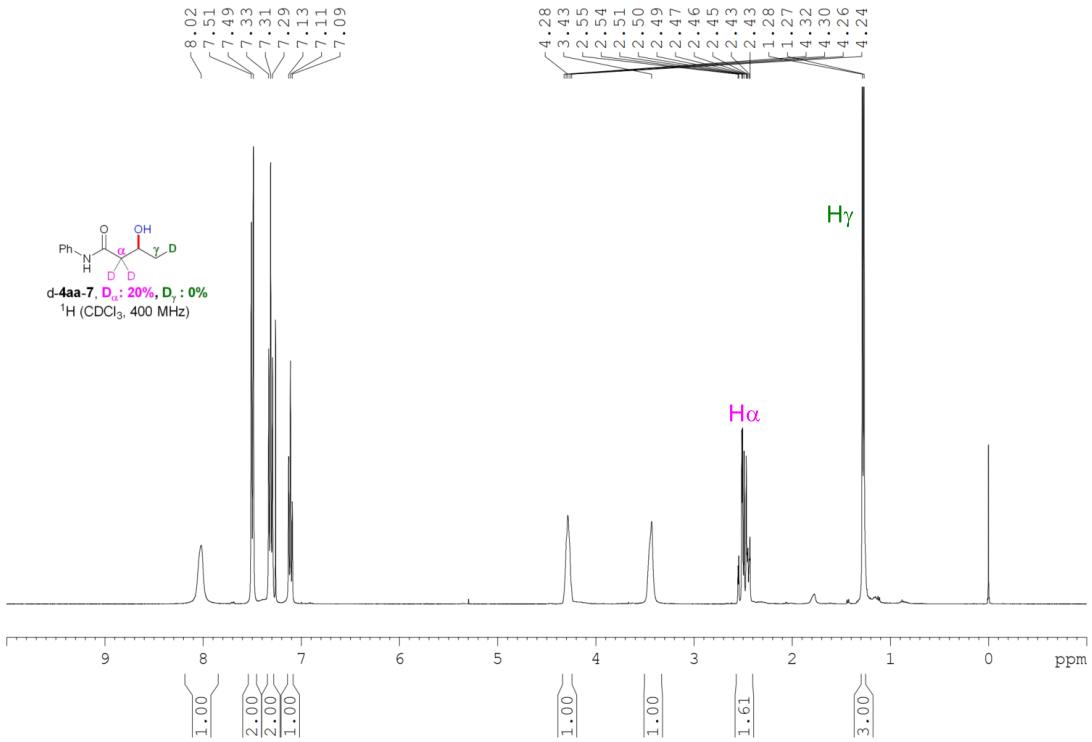
^{13}C NMR Spectra of d-**4aa-6**



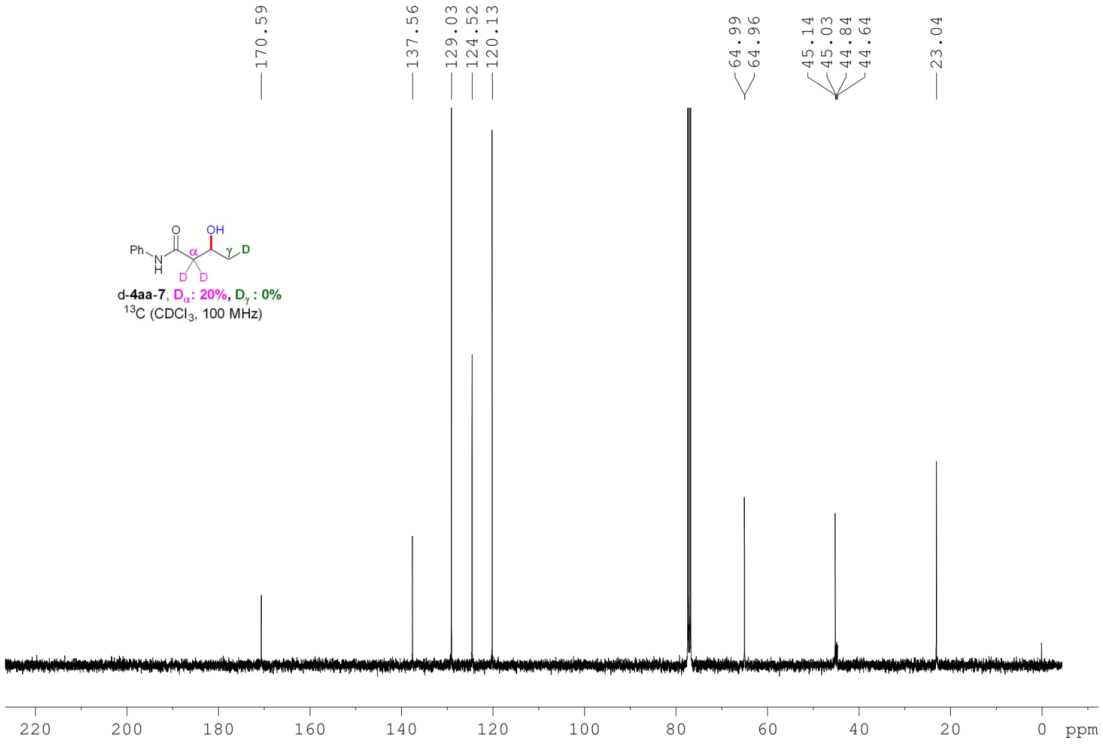
^{2}H NMR Spectra of d-**4aa-6**



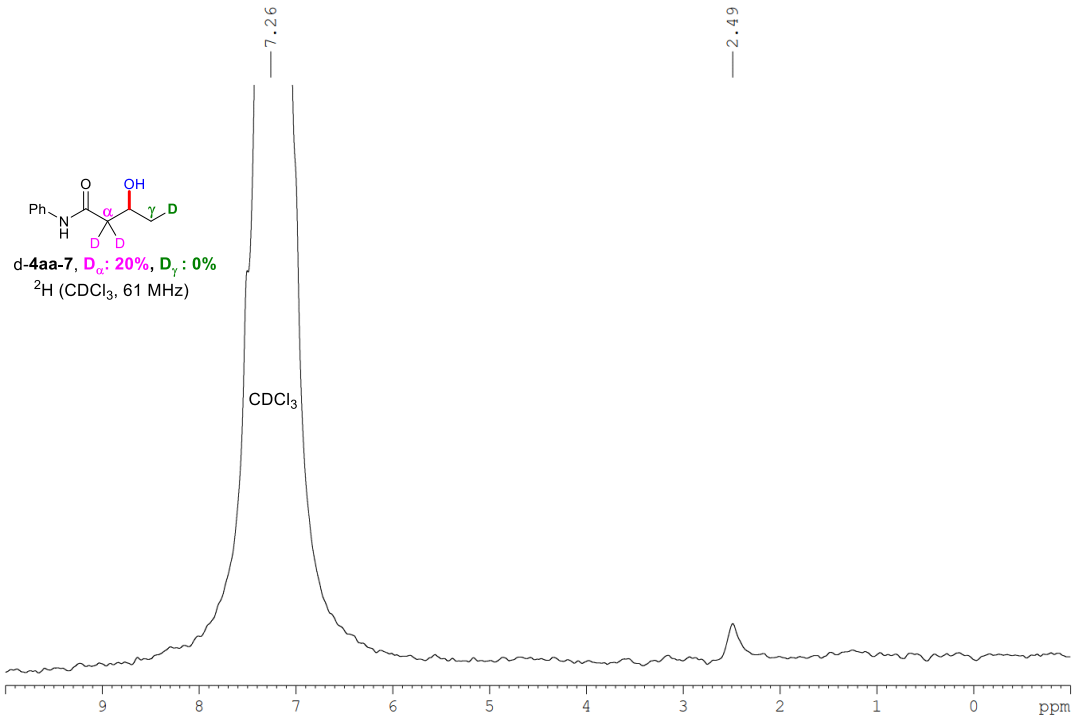
^{1}H NMR Spectra of d-**4aa-7**



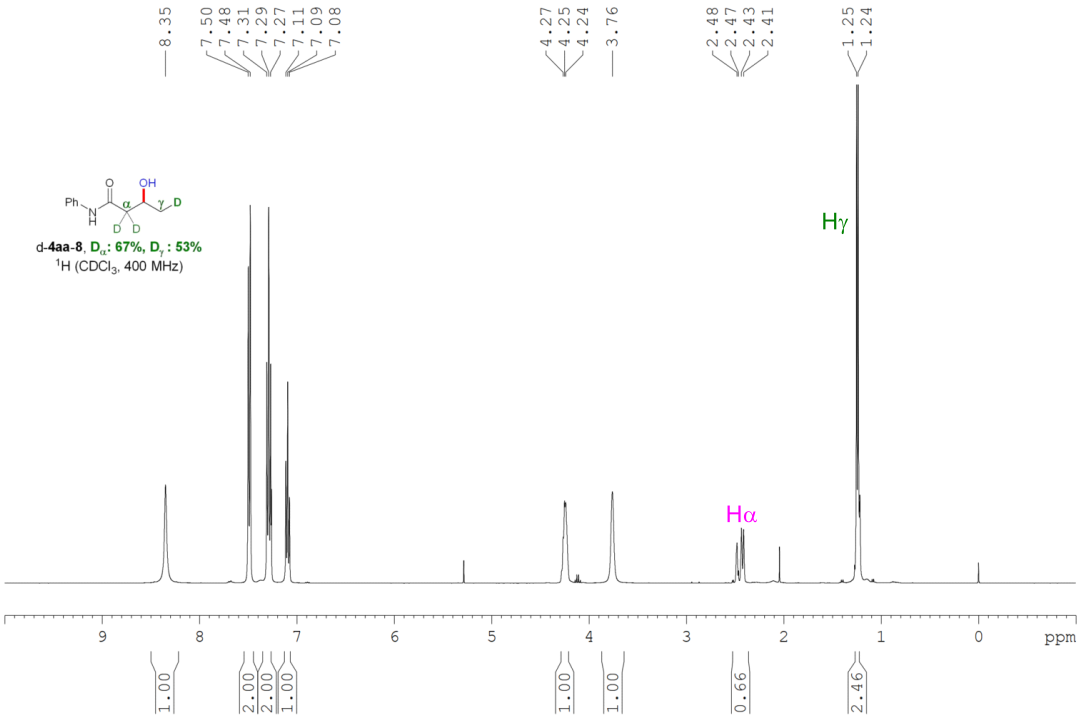
^{13}C NMR Spectra of d-**4aa-7**



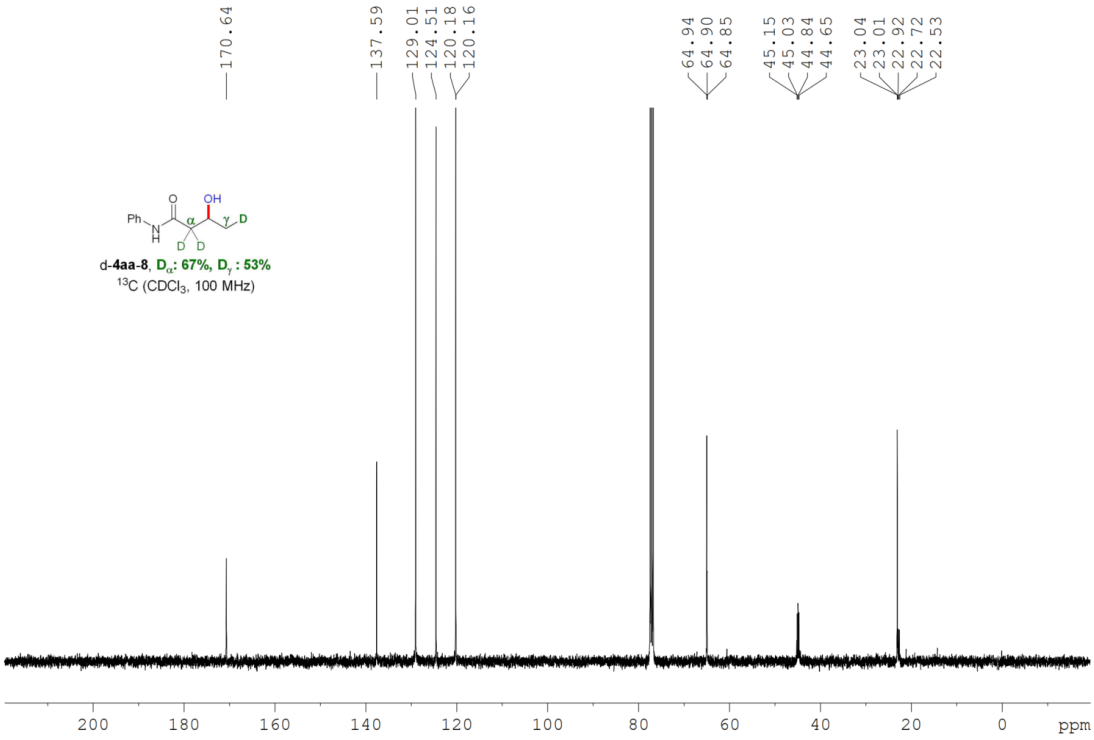
^{2}H NMR Spectra of d-**4aa-7**



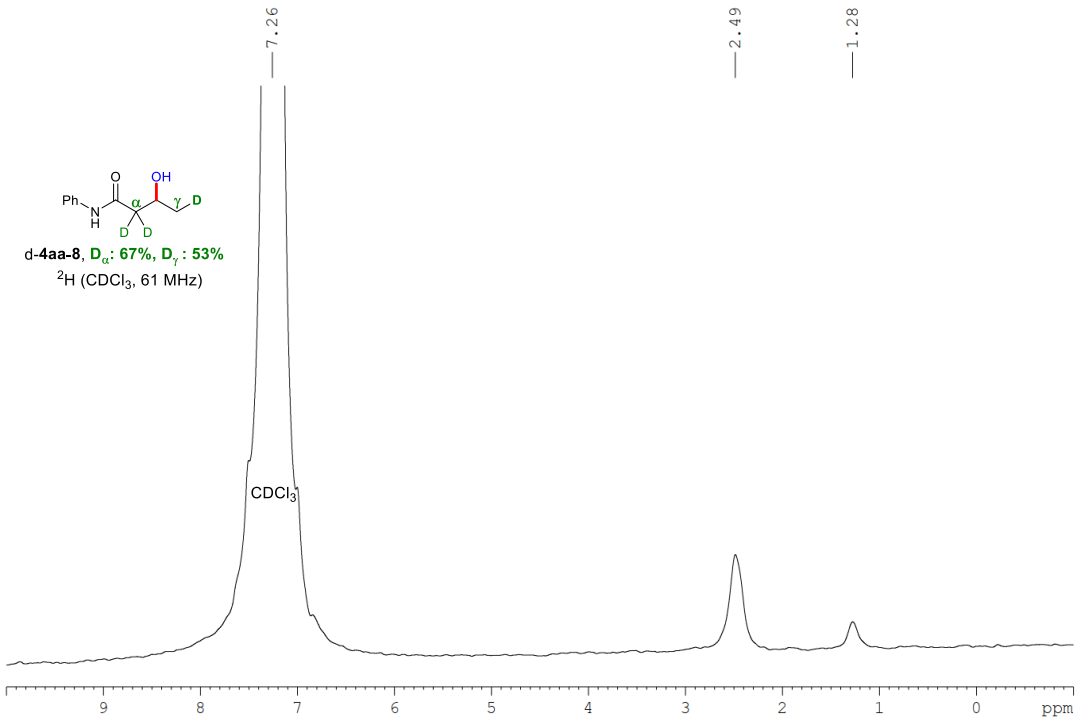
^{1}H NMR Spectra of d-**4aa-8**



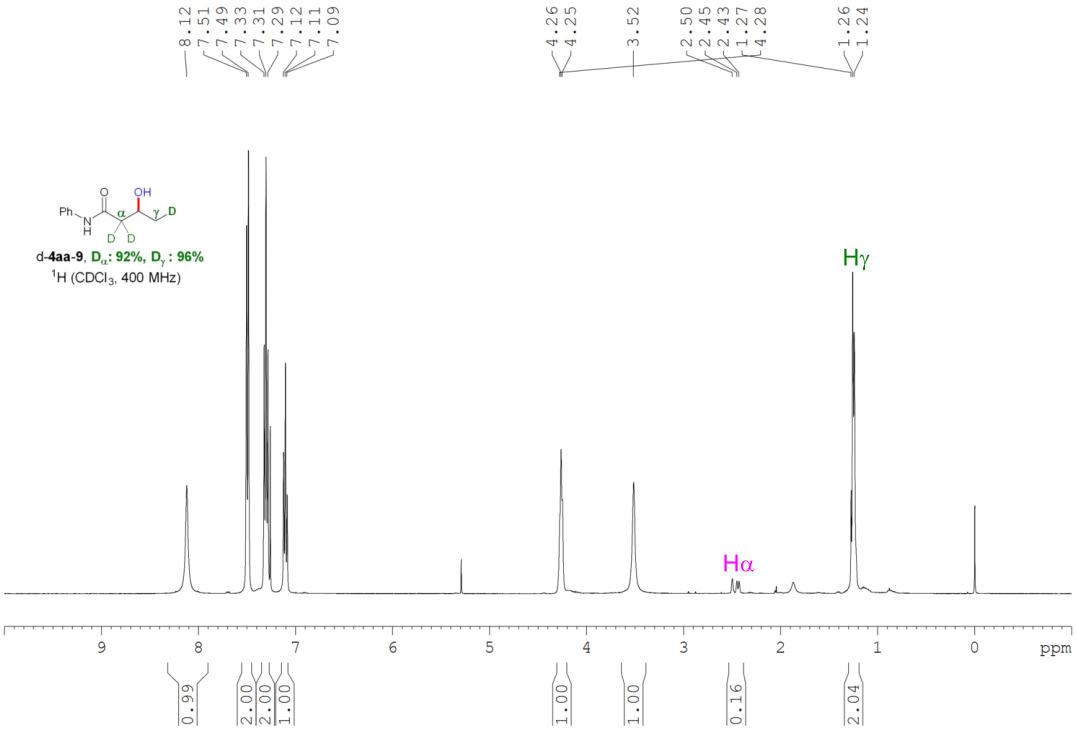
^{13}C NMR Spectra of d-**4aa-8**



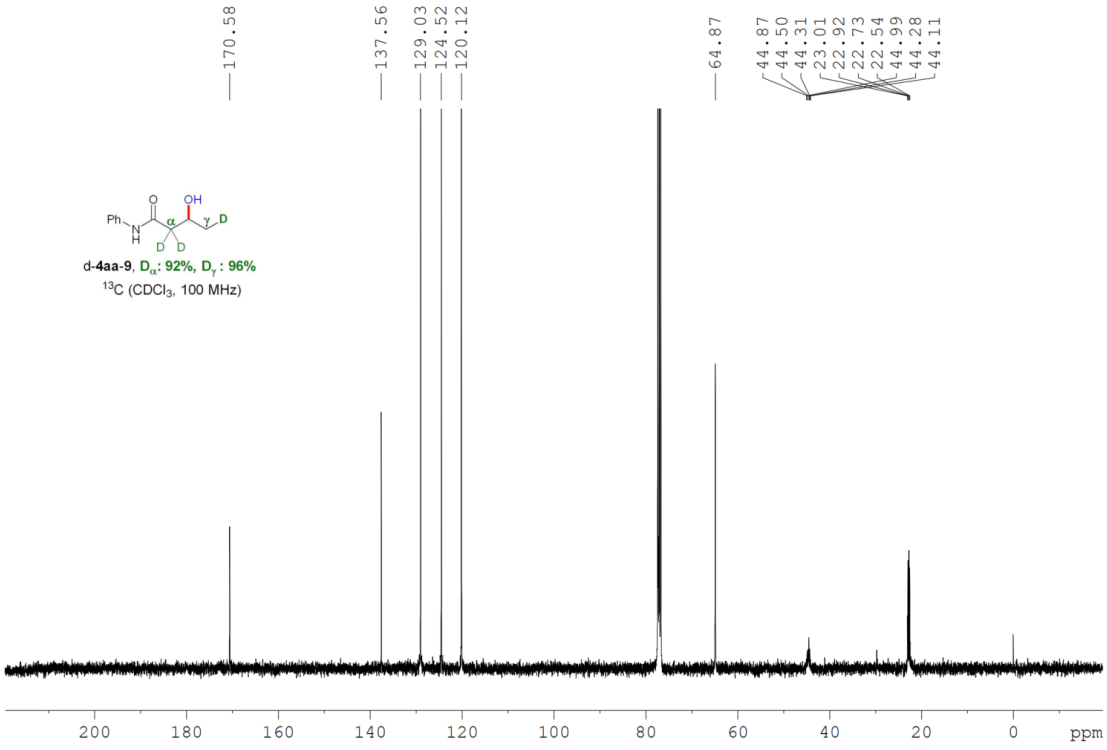
^{2}H NMR Spectra of d-**4aa-8**



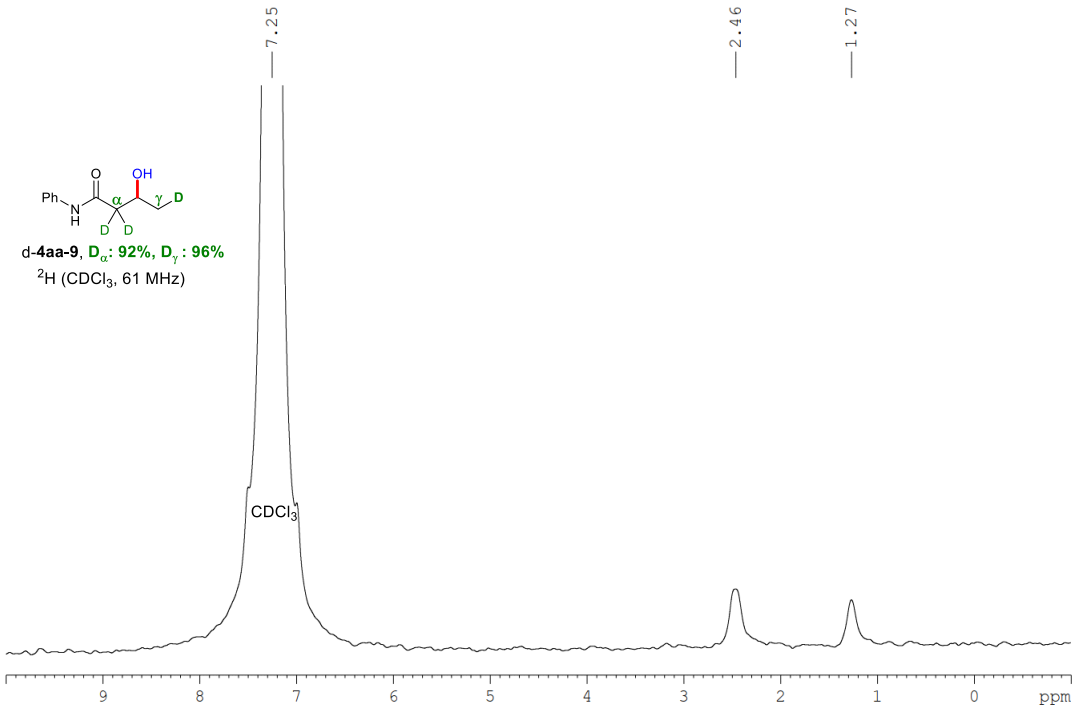
^{1}H NMR Spectra of d-**4aa-9**



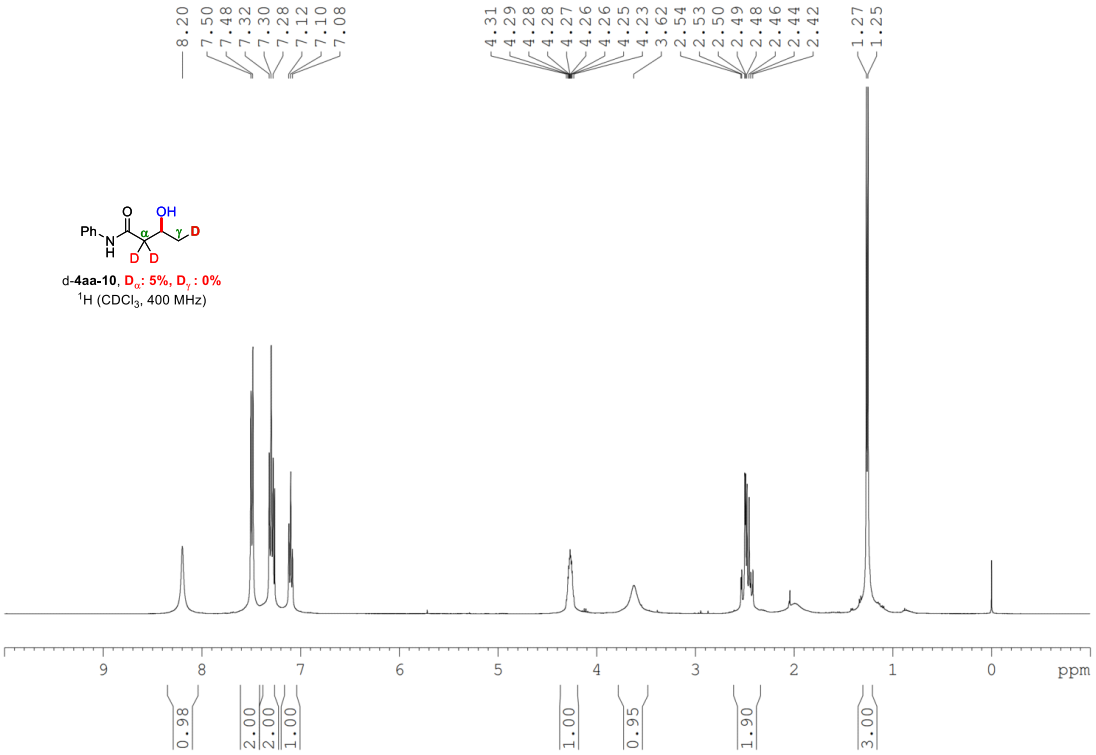
^{13}C NMR Spectra of d-**4aa-9**



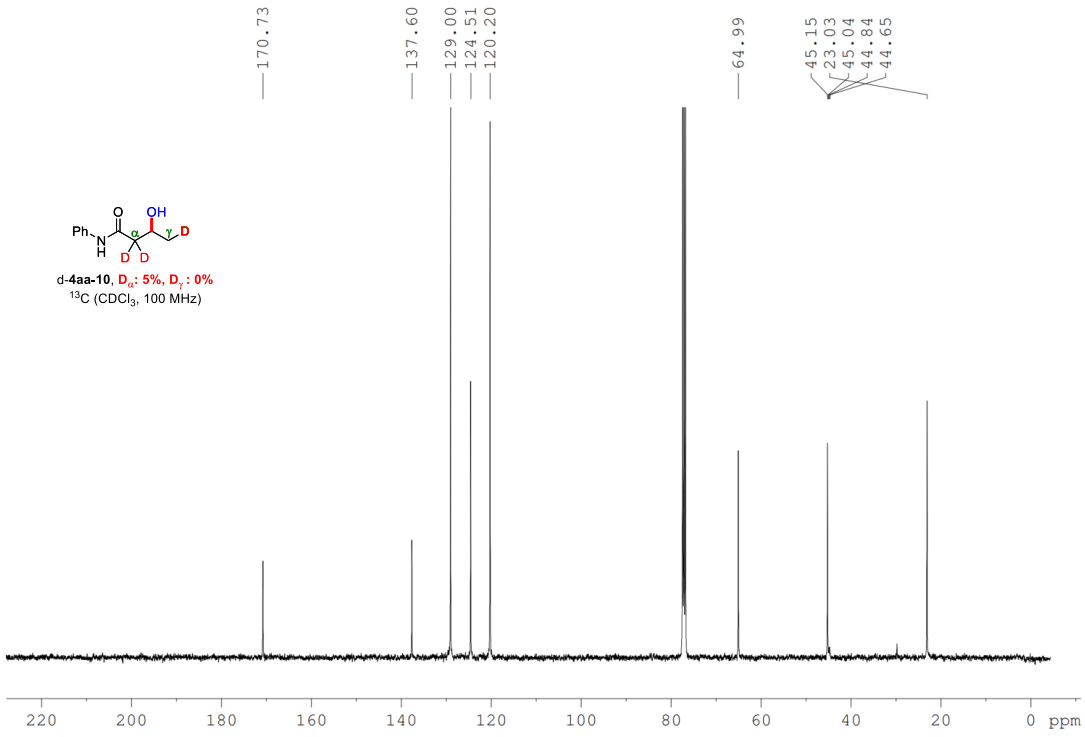
^{2}H NMR Spectra of d-**4aa-9**



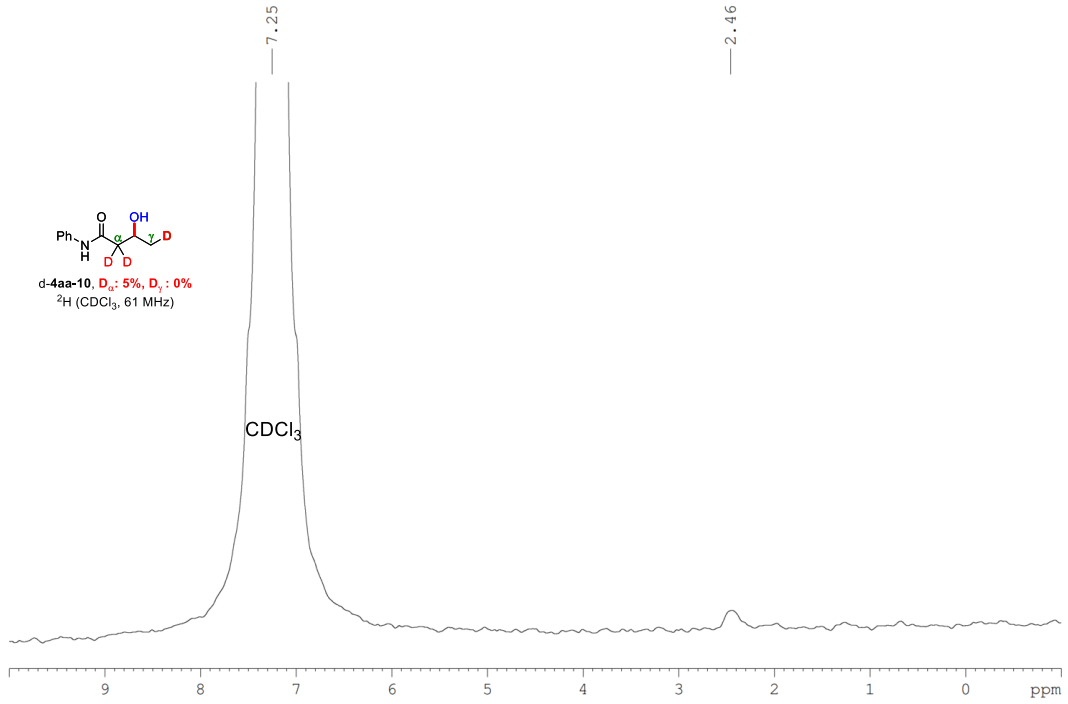
^{1}H NMR Spectra of d-**4aa-10**



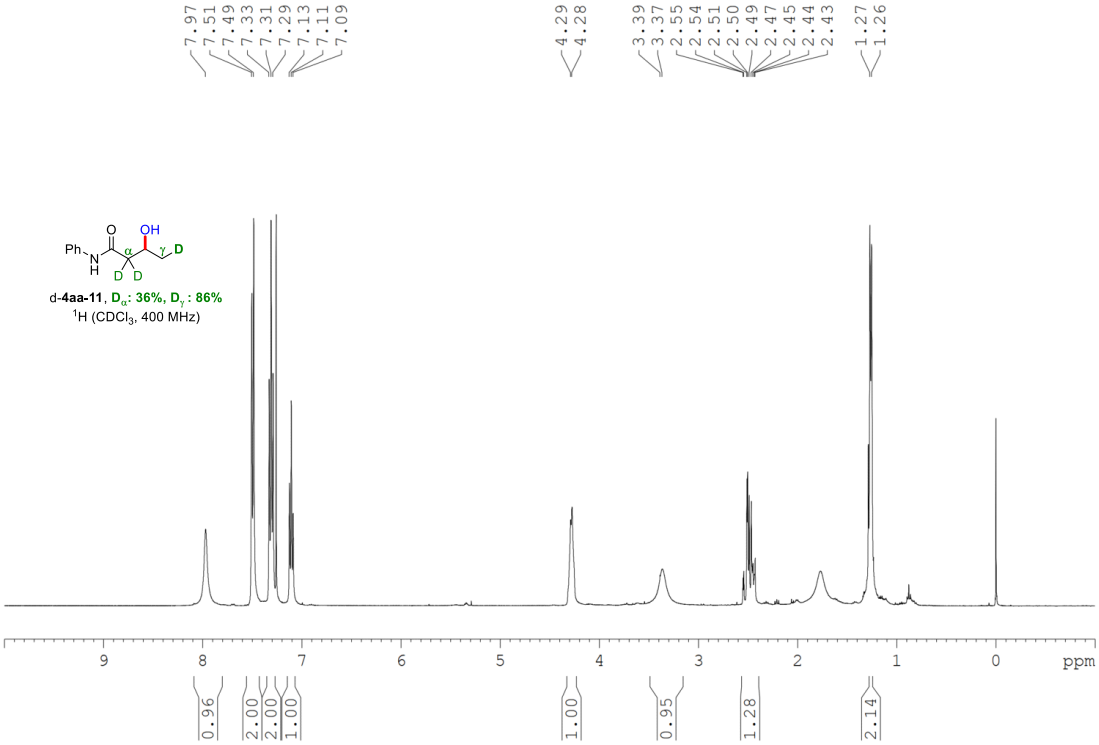
^{13}C NMR Spectra of d-**4aa-10**



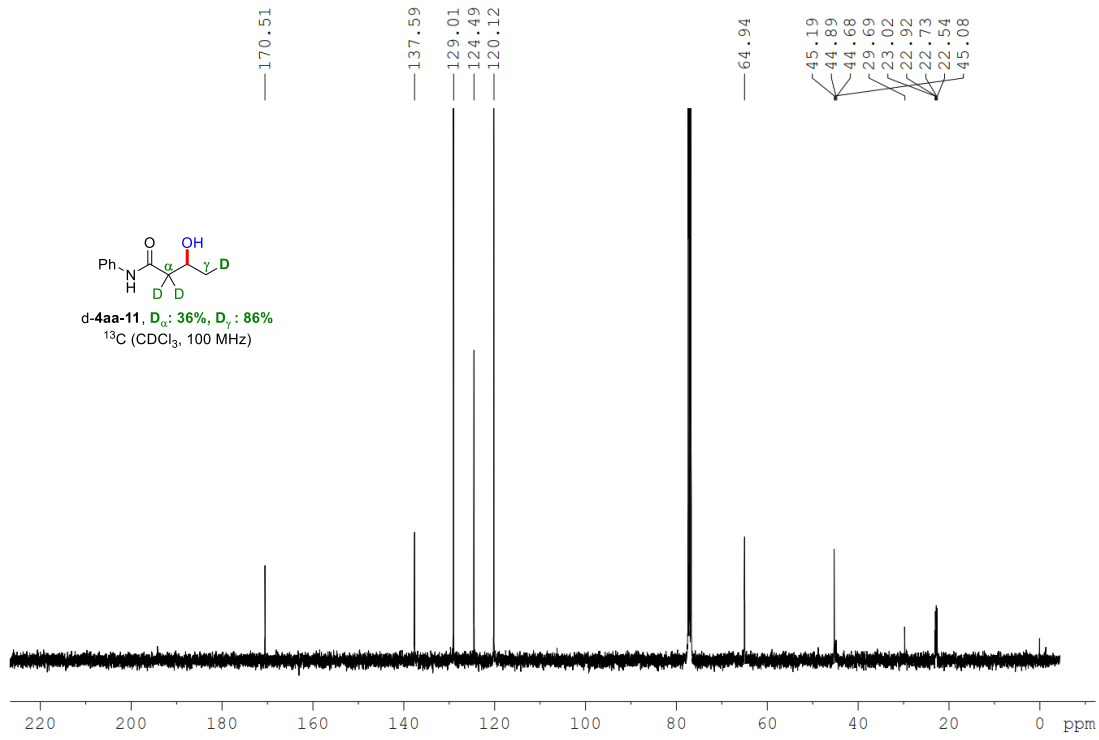
^{2}H NMR Spectra of d-**4aa-10**



^{1}H NMR Spectra of d-**4aa-11**



^{13}C NMR Spectra of d-**4aa-11**



^{2}H NMR Spectra of d-**4aa-11**