N-Heterocyclic Carbene Catalyzed Switchable Reactions of enals with Azoalkenes: Formal [4+3] and [4+1] Annulations for the synthesis of 1,2-Diazepines and Pyrazoles

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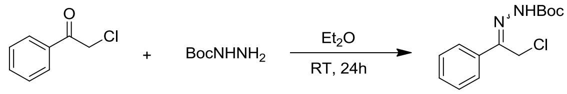
1. General information

Unless otherwise noted, all reactions were carried out under an atmosphere of argon in flame-dried glassware. Reaction temperatures are reported as the temperature of the bath surrounding the vessel unless otherwise stated. The solvents used were purified by distillation over the drying agents indicated in parentheses and were transferred under argon: n-hexane (CaH_2), THF (Na-benzophenone), toluene (CaH_2).

Analytical thin layer chromatography was performed on Polygram SIL G/UV254 plates. Flash chromatography was either performed on Merck silica gel (40-63 mesh) by standard technique eluting with solvents as indicated.

^{1}H and ^{13}C-NMR spectra were recorded on a Bruker AV 300 or AV 400, Varian 500 MHz INOVA or Varian Unity plus 600 in solvents as indicate. Chemical shifts (δ) are given in ppm relative to TMS. The residual solvent signals were used as references and the chemical shifts converted to the TMS scale ($CDCl_3$: δH = 7.26 ppm, δC = 77.16 ppm). ESI mass spectra were recorded on a Bruker Daltonics MicroTof. Specific rotation was measured on a Perkin Elmer 341 polarimeter at 20 °C using a quartz glass cell (100 mm path length). The enantiomeric ratio (ee) was determined by HPLC analysis using chiral column OD-H and AD-H. No attempts were made to optimize yields for substrate synthesis.

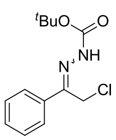
2. Synthesis and characterization of α-chloro N-Boc hydrazones.[1]



2-Chloroacetophenone (3.08 g, 20 mmol) and tert-Butyl carbazate (2.64 g, 20 mmol) were stirred in ether (50 mL) at RT for 24 h. After this time the product had precipitated as a white solid which was collected and dried to give hydrazone as a white powder.

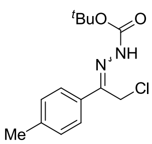
Other hydrazones were synthesized according to the above procedures.

tert-butyl 2-(2-chloro-1-phenylethylidene)hydrazinecarboxylate (2d)



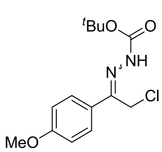
^{1}H NMR (300 MHz, $CDCl_3$) δ 8.19 (s, 1H), 7.84 – 7.75 (m, 2H), 7.45 – 7.35 (m, 3H), 4.43 (s, 2H), 1.58 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 152.44, 135.51, 129.71, 129.61, 128.64, 126.10, 82.13, 33.69, 28.22, 28.15. **ATR-FTIR (cm^{-1}):** 3198, 2977, 1727, 1699, 1552, 1276, 1253, 1148, 1007, 864, 773; **ESI-MS:** calculated $[C_{13}H_{17}N_2O_2Cl + Na]^+$: 291.0871, found: 291.0869;

tert-butyl 2-(2-chloro-1-(p-tolyl)ethylidene)hydrazinecarboxylate (2e)



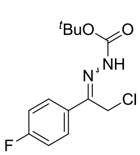
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.71 (s, 1H), 7.27 (d, *J* = 7.9 Hz, 2H), 7.18 – 7.13 (m, 2H), 4.38 (s, 2H), 2.35 (s, 3H), 1.40 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 157.08, 140.32, 130.37, 129.35, 127.44, 126.03, 81.99, 47.92, 28.16, 21.44. **ATR-FTIR (cm^{-1}):** 3190, 2976, 2360, 1699, 1549, 1276, 1253, 1158, 1146, 1004, 821;**ESI-MS:** calculated $[C_{14}H_{19}N_2O_2Cl + Na]^+$: 305.1027, found: 305.1023;

tert-butyl 2-(2-chloro-1-(4-methoxyphenyl)ethylidene)hydrazinecarboxylate (2f)



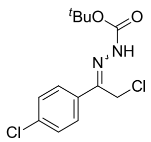
^{1}H NMR (300 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.70 – 7.61 (m, 2H), 6.89 – 6.77 (m, 2H), 4.33 (s, 2H), 3.75 (s, 3H), 1.49 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 160.81, 129.06, 127.61, 115.08, 113.99, 81.92, 55.38, 55.35, 48.03, 28.23, 28.16. **ATR-FTIR (cm^{-1}):** 2979, 1730, 1608, 1510, 1486, 1368, 1246, 1141, 1029, 836, 735; **ESI-MS:** calculated $[C_{14}H_{19}N_2O_3Cl + Na]^+$: 321.0976, found: 321.0971;

tert-butyl 2-(2-chloro-1-(4-fluorophenyl)ethylidene)hydrazinecarboxylate (2g)



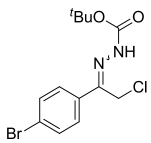
^{1}H NMR (300 MHz, $CDCl_3$) δ 8.11 (s, 1H), 7.75 – 7.65 (m, 2H), 7.07 – 6.96 (m, 2H), 4.33 (s, 2H), 1.49 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 165.28, 131.70, 128.12, 128.01, 115.84, 115.55, 82.23, 33.54, 28.21. **ATR-FTIR (cm^{-1}):** 3056, 2987, 1721, 1699, 1545, 1509, 1370, 1265, 1146, 1005, 839, 732, 705; **ESI-MS:** calculated $[C_{13}H_{16}N_2O_2ClF + Na]^+$: 309.0788, found: 309.0769;

tert-butyl 2-(2-chloro-1-(4-chlorophenyl)ethylidene)hydrazinecarboxylate (2h)



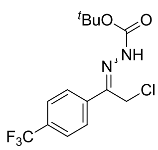
^{1}H NMR (400 MHz, CDCl$_3$) δ 8.25 (s, 1H), 7.77 – 7.69 (m, 2H), 7.42 – 7.34 (m, 2H), 4.40 (s, 2H), 1.58 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 152.24, 135.66, 133.95, 130.10, 129.12, 128.87, 127.37, 82.33, 33.32, 28.21, 28.14. **ATR-FTIR (cm^{-1}):** 3179, 2980, 2362, 1699, 1547, 1490, 1368, 1275, 1253, 1149, 1004, 832; **ESI-MS:** calculated [$C_{13}H_{16}N_2O_2Cl_2$ + Na]$^+$: 325.0492, found: 325.0484;

tert-butyl 2-(1-(4-bromophenyl)-2-chloroethylidene)hydrazinecarboxylate (2i)



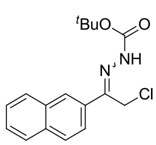
^{1}H NMR (400 MHz, CDCl$_3$) δ 8.11 (s, 1H), 7.61 – 7.55 (m, 2H), 7.49 – 7.42 (m, 2H), 4.31 (s, 2H), 1.50 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 134.38, 131.83, 127.61, 124.02, 82.37, 33.27, 28.20. **ATR-FTIR (cm^{-1}):** 3188, 2980, 1724, 1698, 1602, 1546, 1486, 1460, 1275, 1252, 1160, 1148, 1070, 1003, 831; **ESI-MS:** calculated [$C_{13}H_{16}N_2O_2BrCl$ + Na]$^+$: 370.9966, found: 370.9935;

tert-butyl 2-(2-chloro-1-(4-(trifluoromethyl)phenyl)ethylidene)hydrazinecarboxylate (2j)



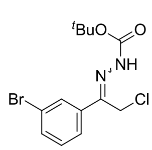
^{1}H NMR (400 MHz, CDCl$_3$) δ 8.29 (s, 1H), 7.82 (d, J = 8.2 Hz, 2H), 7.57 (d, J = 8.3 Hz, 2H), 4.37 (s, 2H), 1.50 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 151.78, 128.33, 126.78, 126.74, 126.35, 125.62, 125.58, 82.53, 47.46, 28.18, 28.11. **ATR-FTIR (cm^{-1}):** 3166, 2363, 1698, 1684, 1598, 1457, 1380, 1327, 1144, 1113, 1065, 1004, 849; **ESI-MS:** calculated [$C_{14}H_{16}N_2O_2ClF_3$ + Na]$^+$: 359.0756, found: 359.0742;

tert-butyl 2-(2-chloro-1-(naphthalen-2-yl)ethylidene)hydrazinecarboxylate (2k)



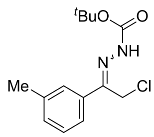
^{1}H NMR (300 MHz, CDCl$_3$) δ 8.33 (s, 1H), 8.14 – 8.03 (m, 2H), 7.86 (dt, J = 9.4, 5.5 Hz, 3H), 7.57 – 7.45 (m, 2H), 4.55 (s, 2H), 1.60 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 152.39, 133.82, 133.00, 132.83, 128.57, 128.51, 127.70, 126.97, 126.52, 125.69, 123.51, 82.21, 33.46, 28.26, 28.15. **ATR-FTIR (cm^{-1}):** 3174, 2981, 1731, 1698, 1552, 1465, 1253, 1154, 1077, 1013, 943, 815; **ESI-MS:** calculated [$C_{17}H_{19}N_2O_2Cl$ + Na]$^+$: 341.1038, found: 341.1027;

tert-butyl 2-(1-(3-bromophenyl)-2-chloroethylidene)hydrazinecarboxylate (2l)



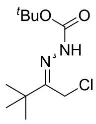
^{1}H NMR (300 MHz, CDCl$_3$) δ 8.61 (s, 1H), 7.94 – 7.87 (m, 1H), 7.63 (ddd, J = 5.7, 3.7, 2.0 Hz, 1H), 7.50 – 7.41 (m, 1H), 7.21 (ddd, J = 6.8, 4.3, 2.9 Hz, 1H), 4.41 (s, 2H), 1.54 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 152.78, 137.61, 132.36, 130.09, 129.03, 124.63, 122.86, 95.15, 82.32, 47.58, 28.22. **ATR-FTIR (cm^{-1}):** 3194, 2982, 1730, 1700, 1549, 1473, 1369, 1280, 1250, 1146, 1013, 782; **ESI-MS:** calculated [$C_{13}H_{16}N_2O_2BrCl$ + Na]$^+$: 370.9966, found: 370.9948;

tert-butyl 2-(2-chloro-1-(m-tolyl)ethylidene)hydrazinecarboxylate (2m)



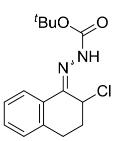
^{1}H NMR (300 MHz, CDCl$_3$) δ 7.76 (s, 1H), 7.42 – 7.33 (m, 1H), 7.22 (d, *J* = 7.8 Hz, 1H), 7.06 (d, *J* = 5.5 Hz, 2H), 4.40 (s, 2H), 2.37 (s, 3H), 1.44 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 152.13, 139.64, 135.48, 130.93, 129.55, 127.83, 124.54, 81.80, 47.84, 28.13, 21.49. **ATR-FTIR (cm^{-1}):** 2980, 1745, 1486, 1368, 1238, 1153, 1105, 1019, 854, 713; **ESI-MS:** calculated [$C_{14}H_{19}N_2O_2Cl$ + Na]$^+$: 305.1038, found: 305.1022;

tert-butyl 2-(1-chloro-3,3-dimethylbutan-2-ylidene)hydrazinecarboxylate (2n)



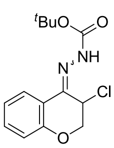
^{1}H NMR (400 MHz, CDCl$_3$) δ 7.99 (s, 1H), 4.04 (s, 2H), 1.53 (s, 9H), 1.21 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 152.61, 81.43, 38.59, 32.86, 28.27, 27.51. **ATR-FTIR (cm^{-1}):** 3206, 2977, 2364, 1701, 1551, 1367, 1276, 1252, 1150, 1019, 875; **ESI-MS:** calculated [$C_{11}H_{21}N_2O_2Cl$ + Na]$^+$: 271.1184, found: 271.1182;

tert-butyl 2-(2-chloro-3,4-dihydronaphthalen-1(2H)-ylidene)hydrazinecarboxylate (2o)



^{1}H NMR (400 MHz, CDCl$_3$) δ 8.16 (d, *J* = 5.8 Hz, 2H), 7.24 – 7.13 (m, 2H), 7.08 (dd, *J* = 8.3, 7.6 Hz, 1H), 4.97 (t, *J* = 3.4 Hz, 1H), 3.17 (ddd, *J* = 16.4, 12.2, 4.2 Hz, 1H), 2.65 (dt, *J* = 16.3, 3.6 Hz, 1H), 2.34 – 2.13 (m, 2H), 1.50 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 146.51, 137.61, 129.75, 129.43, 128.26, 126.88, 125.48, 81.94, 48.95, 31.22, 28.25, 24.08. **ATR-FTIR (cm^{-1}):** 2980, 1702, 1487, 1394, 1368, 1248, 1146, 1068, 1010, 860, 722; **ESI-MS:** calculated [$C_{15}H_{19}N_2O_2Cl$ + Na]$^+$: 317.1038, found: 317.1026;

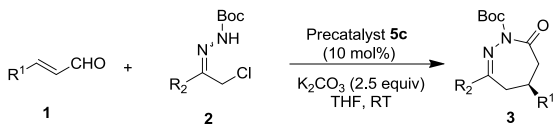
tert-butyl 2-(3-chlorochroman-4-ylidene)hydrazinecarboxylate (2p)



^{1}H NMR (300 MHz, CDCl$_3$) δ 8.11 (t, *J* = 6.3 Hz, 2H), 7.36 – 7.27 (m, 1H), 7.07 – 7.00 (m, 1H), 6.97 (dd, *J* = 8.3, 0.8 Hz, 1H), 4.87 (dd, *J* = 3.7, 1.9 Hz, 1H), 4.51 (dd, *J* = 12.8, 1.9 Hz, 1H), 4.36 (dd, *J* = 12.9, 2.3 Hz, 1H), 1.57 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 155.55, 131.40, 125.47, 122.58, 117.48, 82.27, 70.05, 45.35, 28.22. **ATR-FTIR (cm^{-1}):** 3140, 2982, 1693, 1615, 1497, 1369, 1217, 1148, 1027, 982, 758; **ESI-MS:** calculated [$C_{14}H_{17}N_2O_3Cl$ + Na]$^+$: 319.0831, found: 319.0827;

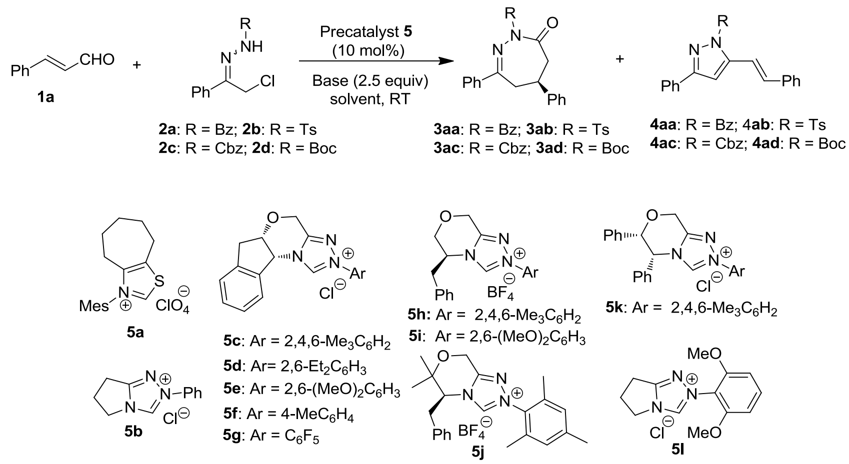
3. Synthesis and Characterization of Products

General procedure for enantioselective synthesis of 3 by formal [4+3] cycloaddition of in situ-derived azoalkenes and enals.



A dried and argon-filled Schlenk flask was charged with hydrazone **2** (0.2 mmol, 1.0 equiv) and K_2CO_3 (0.5 mmol). Then, enal **1** (0.4 mmol) was added quickly to the mixture. Subsequently, triazolium salt **5c** (0.02 mmol, 10 mol%) in 2.5 mL THF was added to the mixture. The mixture was stirred at RT for 16 h. After purification by column chromatography on silica gel (Pentane: Ethyl acetate = 4:1) the desired product **3** was obtained.

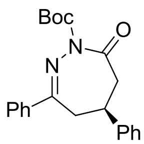
Optimization of the reaction conditions.[a]



entry	Precat.	**2**	Base	Solvent	Yield (%)[b]	**3/4**[c]	*ee* of **3** (%)[d]
1	**5a**	**2a**	K_2CO_3	THF	trace	-	-
2	**5b**	**2a**	K_2CO_3	THF	trace	-	-
3	**5c**	**2a**	K_2CO_3	THF	52	2:3	91
4	**5c**	**2b**	K_2CO_3	THF	50	>20:1	21
5	**5c**	**2c**	K_2CO_3	THF	37	4:1	98
6	**5c**	**2d**	$\mathbf{K_2CO_3}$	**THF**	**77**	**9:1**	**99**
7	**5c**	**2d**	Na_2CO_3	THF	25	8:1	99
8	**5c**	**2d**	DIPEA	THF	49	9:1	99
9	**5c**	**2d**	DBU	THF	trace	-	-
10	**5c**	**2d**	NaOAc	THF	22	5:1	99
11	**5c**	**2d**	Cs_2CO_3	THF	70	6:1	99
12	**5c**	**2d**	K_2CO_3	DCM	trace	-	-
13	**5c**	**2d**	K_2CO_3	toluene	trace	-	-
14	**5c**	**2d**	K_2CO_3	DME	36	7:1	99
15	**5c**	**2d**	K_2CO_3	Dioxane	45	5:1	99
16	**5c**	**2d**	K_2CO_3	$CHCl_3$	trace	-	-
17	**5c**	**2d**	K_2CO_3	Et_2O	trace	-	-
18	**5d**	**2d**	K_2CO_3	THF	42	8:1	99
19	**5e**	**2d**	K_2CO_3	THF	75	1:2	99
20	**5f**	**2d**	K_2CO_3	THF	12	6:1	99
21	**5g**	**2d**	K_2CO_3	THF	trace	-	-
22	**5h**	**2d**	K_2CO_3	THF	52	6:1	99
23[e]	**5i**	**2d**	$\mathbf{K_2CO_3}$	**THF**	**64**	**<1:20**	**-**
24	**5j**	**2d**	K_2CO_3	THF	trace	-	-
25	**5k**	**2d**	K_2CO_3	THF	trace	-	-
26	**5l**	**2d**	K_2CO_3	THF	19	<1:20	-

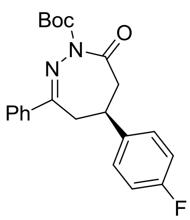
[a]Conditions: **1a** (0.2 mmol), **2a** (0.1 mmol), chiral precatalyst (10 mol %), base (250 mol %), THF (1.5 mL), room temperature, 16 h. [b]Yield of the isolated product after column chromatograpy, and combined yield of **3** and **4**. [c]determined by ^{1}H NMR spectroscopy. [d]The *ee* value of **3** was determined by HPLC using a chiral column. [e]After 16 h, 6.0 equiv TsOH was added.

(S)-tert-butyl 7-oxo-3,5-diphenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ad)



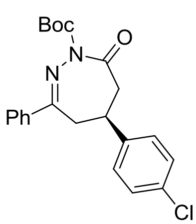
Total yield: 50 mg (70%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.70 – 7.62 (m, 2H), 7.42 – 7.29 (m, 3H), 7.26 – 7.16 (m, 5H), 3.76 – 3.62 (m, 1H), 3.17 (dd, *J* = 13.2, 6.8 Hz, 1H), 3.00 (dd, *J* = 13.2, 9.0 Hz, 1H), 2.84 – 2.68 (m, 2H), 1.53 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.28, 168.68, 149.98, 142.23, 135.62, 131.15, 128.94, 128.70, 127.52, 127.40, 126.84, 83.93, 43.77, 41.00, 35.24, 28.05. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1736, 1453, 1369, 1245, 1145, 1025, 848, 757, 696; **ESI-MS:** calculated $[C_{22}H_{24}N_2O_3 + Na]^+$: 387.1679, found: 387.1679; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 6.5 min, t_2(minor) = 15.3 min.

(S)-tert-butyl 5-(4-fluorophenyl)-7-oxo-3-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3bd)



Total yield: 45 mg (60%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.73 – 7.64 (m, 2H), 7.46 – 7.30 (m, 3H), 7.24 – 7.13 (m, 2H), 7.00 – 6.89 (m, 2H), 3.76 – 3.63 (m, 1H), 3.16 (dd, *J* = 13.2, 6.7 Hz, 1H), 2.97 (dd, *J* = 13.2, 9.4 Hz, 1H), 2.80 (dd, *J* = 12.6, 7.8 Hz, 1H), 2.68 (dd, *J* = 12.6, 5.4 Hz, 1H), 1.53 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.10, 168.51, 135.50, 131.26, 128.77, 128.52, 128.41, 127.35, 115.92, 115.63, 110.00, 109.57, 84.06, 43.12, 41.19, 35.30, 28.03. **^{19}F NMR (282 MHz, CDCl$_3$)** δ -114.9. **ATR-FTIR (cm^{-1}):** 2982, 1769, 1736, 1511, 1369, 1247, 1228, 1147, 837, 759; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3F + Na]^+$: 405.1585, found: 405.1582; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.9 min, t_2(minor) = 8.6 min.

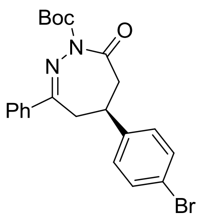
(S)-tert-butyl 5-(4-chlorophenyl)-7-oxo-3-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3cd)



Total yield: 40 mg (51%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.70 (dd, *J* = 8.2, 1.4 Hz, 2H), 7.45 – 7.31 (m, 3H), 7.27 – 7.13 (m, 4H), 3.66 (dt, *J* = 14.5, 7.1 Hz, 1H), 3.15 (dd, *J* = 13.2, 6.7 Hz, 1H), 2.96 (dd, *J* = 13.2, 9.5 Hz, 1H), 2.80 (dd, *J* = 12.7, 7.8 Hz, 1H), 2.67 (dd, *J* = 12.7, 5.3 Hz, 1H), 1.53 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 168.99, 168.44, 149.90, 140.72, 135.45, 133.33, 131.30, 129.07, 128.80, 128.27, 127.33, 84.10, 43.24, 41.04, 35.07, 28.02. **ATR-FTIR (cm^{-1}):**

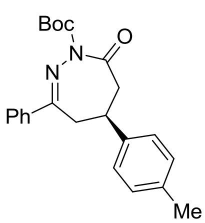
2981, 1770, 1736, 1494, 1369, 1265, 1248, 1148, 1094, 1014, 732; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3Cl + Na]^+$: 421.1289, found: 421.1293; The product was analyzed by HPLC to determine the enantiomeric excess: 93% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 6.3 min, t_2(minor) = 8.3 min.

(S)-tert-butyl 5-(4-bromophenyl)-7-oxo-3-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3dd)



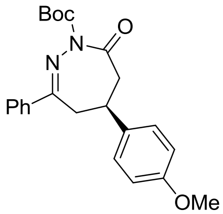
Total yield: 35 mg (40%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.72 – 7.67 (m, 2H), 7.44 – 7.32 (m, 5H), 7.15 – 7.08 (m, 2H), 3.65 (dt, *J* = 19.9, 7.3 Hz, 1H), 3.15 (dd, *J* = 13.2, 6.7 Hz, 1H), 2.96 (dd, *J* = 13.2, 9.5 Hz, 1H), 2.79 (dd, *J* = 12.7, 7.9 Hz, 1H), 2.67 (dd, *J* = 12.7, 5.2 Hz, 1H), 1.53 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 168.96, 168.42, 141.25, 135.46, 132.04, 131.31, 128.82, 128.62, 127.33, 121.42, 84.11, 43.31, 40.99, 34.99, 28.03. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1734, 1490, 1369, 1265, 1246, 1147, 1010, 759, 693; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3Br + Na]^+$: 465.0784, found: 465.0780; The product was analyzed by HPLC to determine the enantiomeric excess: 96% *ee* (OD-H, hexane/*i*-PrOH = 85/15, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 10.5 min, t_2(minor) = 16.3 min.

(S)-tert-butyl 7-oxo-3-phenyl-5-(p-tolyl)-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ed)



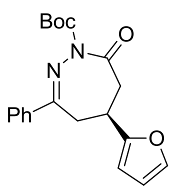
Total yield: 47 mg (63%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.72 – 7.65 (m, 2H), 7.43 – 7.29 (m, 3H), 7.14 – 6.98 (m, 4H), 3.67 (dt, *J* = 14.3, 7.0 Hz, 1H), 3.15 (dd, *J* = 13.2, 6.8 Hz, 1H), 2.99 (dd, *J* = 13.2, 9.0 Hz, 1H), 2.85 – 2.66 (m, 2H), 2.26 (s, 3H), 1.53 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.36, 168.78, 139.27, 137.18, 135.69, 131.10, 129.56, 128.69, 127.42, 126.71, 83.91, 43.48, 41.24, 35.29, 28.04, 21.03. **ATR-FTIR (cm^{-1}):** 2980, 2922, 1769, 1737, 1369, 1265, 1246, 1147, 1048, 847, 758, 693; **ESI-MS:** calculated $[C_{23}H_{26}N_2O_3 + Na]^+$: 401.1836, found: 401.1834; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.3 min, t_2(minor) = 8.4 min.

(S)-tert-butyl 5-(4-methoxyphenyl)-7-oxo-3-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3fd)



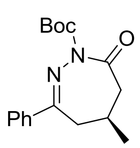
Total yield: 41 mg (52%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.72 – 7.64 (m, 2H), 7.45 – 7.29 (m, 3H), 7.13 (d, *J* = 8.7 Hz, 2H), 6.79 (t, J = 5.9 Hz, 2H), 3.72 (s, 3H), 3.65 (dd, *J* = 14.8, 7.4 Hz, 1H), 3.15 (dd, *J* = 13.2, 6.8 Hz, 1H), 2.97 (dd, *J* = 13.2, 8.9 Hz, 1H), 2.73 (qd, *J* = 12.5, 6.8 Hz, 2H), 1.53 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.35, 168.73, 158.86, 149.99, 135.69, 134.37, 131.11, 128.70, 127.91, 127.42, 114.22, 83.90, 55.31, 43.12, 41.36, 35.42, 28.04. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1736, 1611, 1515, 1369, 1247, 1148, 1031, 835, 759, 693; **ESI-MS:** calculated [$C_{23}H_{26}N_2O_4$ + Na]$^+$: 417.1785, found: 417.1787; **HPLC**(OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 7.2 min, t_2(minor) = 11.1 min.

(S)-tert-butyl 5-(furan-2-yl)-7-oxo-3-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3gd)



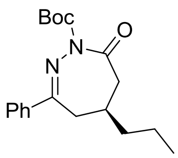
Total yield: 42 mg (60%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.62 – 7.50 (m, 2H), 7.42 – 7.23 (m, 4H), 6.22 (dd, *J* = 3.1, 1.9 Hz, 1H), 6.04 (d, *J* = 3.2 Hz, 1H), 3.81 (p, *J* = 7.2 Hz, 1H), 3.15 (qd, *J* = 13.4, 6.8 Hz, 2H), 2.74 (d, *J* = 7.5 Hz, 2H), 1.52 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 168.42, 168.37, 154.47, 149.80, 141.98, 135.73, 131.08, 128.60, 127.25, 110.48, 106.02, 83.96, 38.92, 37.21, 32.29, 28.02. **ATR-FTIR (cm^{-1}):** 2982, 1770, 1734, 1369, 1245, 1147, 1015, 757, 731, 692; **ESI-MS:** calculated [$C_{20}H_{22}N_2O_4$ + Na]$^+$: 377.1472, found: 377.1478; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.7 min, t_2(minor) = 10.0 min.

(S)-tert-butyl 5-methyl-7-oxo-3-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3hd)



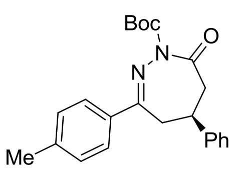
Total yield: 38 mg (62%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.81 (m, 2H), 7.45 – 7.34 (m, 3H), 2.99 – 2.85 (m, 1H), 2.67 – 2.51 (m, 3H), 2.20 – 2.10 (m, 1H), 1.51 (s, 9H), 1.13 (d, *J* = 6.1 Hz, 3H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.35, 169.32, 149.96, 136.14, 131.07, 128.75, 127.24, 83.74, 42.67, 34.65, 33.84, 28.02, 21.46. **ATR-FTIR (cm^{-1}):** 2978, 2362, 1769, 1734, 1458, 1369, 1244, 1148, 1017, 851, 758, 692; **ESI-MS:** calculated [$C_{17}H_{22}N_2O_3$ + Na]$^+$: 325.1523, found: 325.1525; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.0 min, t_2(minor) = 5.9 min.

(S)-tert-butyl 7-oxo-3-phenyl-5-propyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3id)



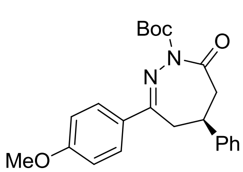
Total yield: 37 mg (57%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.84 – 7.76 (m, 2H), 7.45 – 7.35 (m, 3H), 2.92 (dd, *J* = 12.9, 6.4 Hz, 1H), 2.64 – 2.50 (m, 2H), 2.48 – 2.36 (m, 1H), 2.19 (dd, *J* = 11.9, 4.7 Hz, 1H), 1.51 (s, 9H), 1.40 (dd, *J* = 8.7, 4.1 Hz, 4H), 0.85 (t, *J* = 7.1 Hz, 3H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.59, 169.44, 149.98, 136.20, 131.05, 128.75, 127.19, 83.75, 40.80, 38.48, 37.62, 33.02, 28.02, 20.22, 13.85. **ATR-FTIR (cm^{-1}):** 2960, 1770, 1717, 1456, 1368, 1244, 1148, 851, 757, 693; **ESI-MS:** calculated [$C_{19}H_{26}N_2O_3$ + Na]$^+$: 353.1836, found: 353.1828; The product was analyzed by HPLC to determine the enantiomeric excess: 93% *ee* (OD-H, hexane/*i*-PrOH = 85/15, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.5 min, t_2(minor) = 7.0 min.

(S)-tert-butyl 7-oxo-5-phenyl-3-(p-tolyl)-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ae)



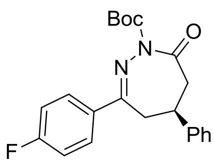
Total yield: 51 mg (68%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.56 (d, *J* = 8.3 Hz, 2H), 7.32 – 7.19 (m, 5H), 7.12 (d, *J* = 8.0 Hz, 2H), 3.74 – 3.62 (m, 1H), 3.16 (dd, *J* = 13.2, 6.8 Hz, 1H), 2.98 (dd, *J* = 13.2, 8.9 Hz, 1H), 2.85 – 2.67 (m, 2H), 2.32 (s, 3H), 1.53 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 169.39, 168.70, 150.02, 142.31, 141.66, 132.77, 129.42, 128.92, 127.48, 127.38, 126.87, 83.86, 43.65, 40.97, 35.09, 28.05, 21.45. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1734, 1454, 1369, 1245, 1146, 847, 759, 734, 700; **ESI-MS:** calculated [$C_{23}H_{26}N_2O_3$ + Na]$^+$: 401.1836, found: 401.1830; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 6.8 min, t_2(minor) = 12.7 min.

(S)-tert-butyl 3-(4-methoxyphenyl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3af)



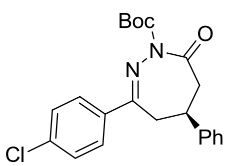
Total yield: 50 mg (64%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.65 – 7.58 (m, 2H), 7.29 – 7.19 (m, 5H), 6.85 – 6.80 (m, 2H), 3.77 (s, 3H), 3.72 – 3.62 (m, 1H), 3.15 (dd, *J* = 13.3, 6.9 Hz, 1H), 2.97 (dd, *J* = 13.3, 8.5 Hz, 1H), 2.80 – 2.69 (m, 2H), 1.53 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 169.47, 168.24, 162.07, 150.07, 142.33, 129.16, 128.92, 127.99, 127.47, 126.89, 114.01, 83.80, 55.42, 43.51, 40.89, 34.92, 28.06. **ATR-FTIR (cm^{-1}):** 2979, 1768, 1735, 1606, 1515, 1455, 1369, 1249, 1149, 1027, 842, 701; **ESI-MS:** calculated [$C_{23}H_{26}N_2O_4$ + Na]$^+$: 417.1785, found: 417.1785; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 9.5 min, t_2(minor) = 16.6 min.

(S)-tert-butyl 3-(4-fluorophenyl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ag)



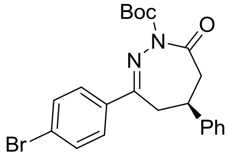
Total yield: 44 mg (58%); **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.69 – 7.60 (m, 2H), 7.29 – 7.19 (m, 5H), 7.04 – 6.94 (m, 2H), 3.71 (p, *J* = 7.1 Hz, 1H), 3.16 (dd, *J* = 13.3, 7.0 Hz, 1H), 2.99 (dd, *J* = 13.3, 8.2 Hz, 1H), 2.76 (d, *J* = 7.0 Hz, 2H), 1.58 – 1.49 (m, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 169.24, 167.46, 162.91, 149.95, 142.00, 131.77, 129.65, 129.53, 128.98, 127.62, 126.81, 115.92, 115.63, 84.06, 43.65, 40.81, 35.20, 28.14, 28.03. **^{19}F NMR (282 MHz, $CDCl_3$)** δ -108.6. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1734, 1602, 1511, 1369, 1235, 1148, 845, 760, 700; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3F + Na]^+$: 405.1585, found: 405.1590; The product was analyzed by HPLC to determine the enantiomeric excess: 98% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 7.3 min, t_2(minor) = 12.6 min.

(S)-tert-butyl 3-(4-chlorophenyl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ah)



Total yield: 56 mg (71%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.60 – 7.54 (m, 2H), 7.30 – 7.19 (m, 7H), 3.71 (p, *J* = 7.2 Hz, 1H), 3.20 – 3.12 (m, 1H), 2.98 (dd, *J* = 13.3, 8.1 Hz, 1H), 2.79 – 2.72 (m, 2H), 1.53 (s, 9H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 169.17, 167.31, 149.93, 141.94, 137.42, 134.06, 129.15, 129.00, 128.92, 128.84, 128.80, 128.71, 127.65, 126.79, 84.12, 43.75, 40.83, 35.11, 28.03, 27.95. **ATR-FTIR (cm^{-1}):** 2982, 1769, 1733, 1369, 1246, 1146, 1092, 1012, 843, 734, 699; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3Cl + Na]^+$: 421.1289, found: 421.1286; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 7.4 min, t_2(minor) = 12.9 min.

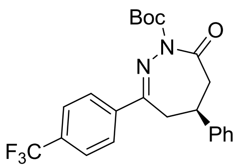
(S)-tert-butyl 3-(4-bromophenyl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ai)



Total yield: 53 mg (60%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.57 – 7.39 (m, 4H), 7.30 – 7.15 (m, 5H), 3.71 (p, *J* = 7.2 Hz, 1H), 3.15 (dd, *J* = 13.3, 7.0 Hz, 1H), 3.03 – 2.92 (m, 1H), 2.79 – 2.73 (m, 2H), 1.53 (s, 9H). **^{13}C NMR**

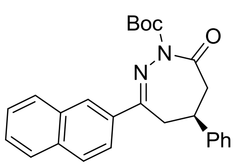
(101 MHz, $CDCl_3$) δ 169.15, 167.38, 149.92, 141.93, 134.51, 131.89, 129.01, 128.90, 127.66, 126.79, 125.90, 84.13, 43.77, 40.83, 35.07, 28.03. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1733, 1369, 1246, 1145, 1073, 1008, 843, 809, 758, 733, 699; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3Br + Na]^+$: 465.0784, found: 465.0783; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 7.7 min, t_2(minor) = 13.0 min.

(S)-tert-butyl 7-oxo-5-phenyl-3-(4-(trifluoromethyl)phenyl)-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3aj)



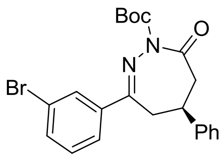
Total yield: 52 mg (61%); **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.73 (d, *J* = 8.2 Hz, 2H), 7.56 (d, *J* = 8.3 Hz, 2H), 7.33 – 7.20 (m, 5H), 3.75 (p, *J* = 7.2 Hz, 1H), 3.20 (dd, *J* = 13.4, 7.0 Hz, 1H), 3.02 (dd, *J* = 13.4, 8.1 Hz, 1H), 2.78 (d, *J* = 7.1 Hz, 2H), 1.55 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 169.08, 166.87, 149.84, 141.76, 129.06, 127.74, 126.74, 125.63, 125.58, 125.53, 84.30, 43.92, 40.83, 35.35, 28.01. **^{19}F NMR (282 MHz, $CDCl_3$)** δ -62.9. **ATR-FTIR (cm^{-1}):** 2983, 1771, 1735, 1323, 1247, 1147, 1125, 1113, 1086, 1015, 848, 738, 700; **ESI-MS:** calculated $[C_{23}H_{23}N_2O_3F_3 + Na]^+$: 455.1553, found: 4551548; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 6.8 min, t_2(minor) = 11.1 min.

(S)-tert-butyl 3-(naphthalen-2-yl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3ak)



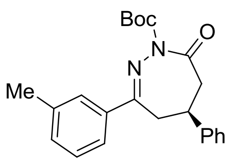
yield: 51 mg (61%); **^{1}H NMR (300 MHz, $CDCl_3$)** δ 8.04 – 7.98 (m, 1H), 7.78 (dd, *J* = 8.4, 3.4 Hz, 2H), 7.71 (d, *J* = 1.4 Hz, 1H), 7.65 – 7.58 (m, 1H), 7.50 – 7.38 (m, 2H), 7.31 – 7.21 (m, 5H), 3.81 (p, *J* = 7.2 Hz, 1H), 3.32 (dd, *J* = 13.3, 7.1 Hz, 1H), 3.11 (dd, *J* = 13.3, 7.9 Hz, 1H), 2.80 (d, *J* = 7.1 Hz, 2H), 1.56 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 169.47, 168.33, 150.02, 142.22, 134.49, 133.01, 132.70, 128.98, 128.91, 128.63, 128.49, 127.70, 127.59, 126.95, 126.67, 123.75, 84.02, 43.71, 40.74, 35.27, 28.07. **ATR-FTIR (cm^{-1}):** 2981, 1767, 1732, 1454, 1369, 1246, 1144, 1051, 811, 757, 733, 699; **ESI-MS:** calculated $[C_{26}H_{26}N_2O_3 + Na]^+$: 437.1836, found: 437.1824; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 8.4 min, t_2(minor) = 14.0 min.

(S)-tert-butyl 3-(3-bromophenyl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3al)



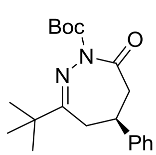
Total yield: 53 mg (60%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.77 (t, *J* = 1.8 Hz, 1H), 7.51 (m, 2H), 7.30 – 7.14 (m, 6H), 3.77 – 3.67 (m, 1H), 3.15 (dd, *J* = 13.3, 6.9 Hz, 1H), 3.05 – 2.92 (m, 1H), 2.76 (d, *J* = 7.0 Hz, 2H), 1.54 (s, 9H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 169.11, 167.08, 149.87, 141.84, 137.69, 133.96, 130.49, 130.12, 129.02, 127.71, 126.77, 125.95, 122.94, 84.21, 43.79, 40.81, 35.34, 28.02. **ATR-FTIR (cm^{-1}):** 2980, 1770, 1735, 1454, 1369, 1244, 1145, 1051, 849, 759, 735, 700; **ESI-MS:** calculated $[C_{22}H_{23}N_2O_3Br + Na]^+$: 465.0784, found: 465.0783; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 7.7 min, t_2(minor) = 14.3 min.

(S)-tert-butyl 7-oxo-5-phenyl-3-(m-tolyl)-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3am)



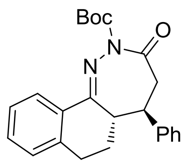
Total yield: 50 mg (67%); **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.43 (dd, *J* = 9.1, 4.2 Hz, 2H), 7.29 – 7.19 (m, 7H), 3.76 – 3.64 (m, 1H), 3.17 (dd, *J* = 13.2, 6.9 Hz, 1H), 2.99 (dd, *J* = 13.2, 8.9 Hz, 1H), 2.86 – 2.69 (m, 2H), 2.27 (s, 3H), 1.54 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 169.31, 169.04, 150.01, 142.26, 138.42, 135.60, 131.92, 128.92, 128.55, 128.08, 127.50, 126.88, 124.59, 83.93, 43.67, 40.88, 35.40, 28.05, 21.41. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1735, 1454, 1369, 1247, 1147, 1052, 759, 734, 698; **ESI-MS:** calculated $[C_{23}H_{26}N_2O_3 + Na]^+$: 401.1836, found: 401.1836; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.8 min, t_2(minor) = 12.0 min.

(S)-tert-butyl 3-(tert-butyl)-7-oxo-5-phenyl-4,5,6,7-tetrahydro-1H-1,2-diazepine-1-carboxylate (3an)



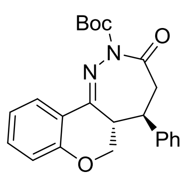
Total yield: 50 mg (73%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.57 – 7.39 (m, 4H), 7.30 – 7.15 (m, 5H), 3.71 (p, *J* = 7.2 Hz, 1H), 3.15 (dd, *J* = 13.3, 7.0 Hz, 1H), 3.03 – 2.92 (m, 1H), 2.79 – 2.73 (m, 2H), 1.53 (s, 9H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 179.88, 168.74, 149.85, 142.78, 128.90, 127.32, 126.74, 83.33, 43.43, 40.69, 39.54, 33.74, 28.00, 27.62. **ATR-FTIR (cm^{-1}):** 2976, 1768, 1737, 1456, 1368, 1267, 1245, 1149, 1025, 758, 734, 699; **ESI-MS:** calculated $[C_{20}H_{28}N_2O_3 + Na]^+$: 367.1992, found: 367.1987; The product was analyzed by HPLC to determine the enantiomeric excess: 98% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 4.2 min, t_2(minor) = 8.7 min.

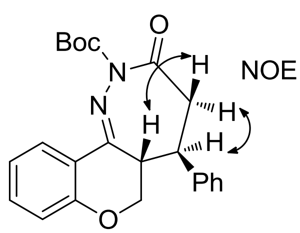
(5R,5aS)-tert-butyl 3-oxo-5-phenyl-3,4,5,5a,6,7-hexahydro-2H-naphtho[1,2-c][1,2]diazepine-2-carboxylate (3ao)



Total yield: 51 mg (65%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 8.32 – 8.26 (m, 1H), 7.25 – 7.20 (m, 2H), 7.15 – 7.09 (m, 1H), 7.03 (t, *J* = 7.4 Hz, 2H), 6.92 (d, *J* = 7.2 Hz, 2H), 6.84 – 6.77 (m, 1H), 3.75 – 3.63 (m, 1H), 3.50 (td, *J* = 7.4, 3.6 Hz, 1H), 2.97 (t, *J* = 12.4 Hz, 1H), 2.60 (dd, *J* = 12.1, 5.9 Hz, 1H), 2.19 (dt, *J* = 16.7, 5.2 Hz, 1H), 1.97 (ddt, *J* = 12.8, 11.2, 6.3 Hz, 1H), 1.66 (ddd, *J* = 13.9, 8.8, 5.0 Hz, 1H), 1.52 (s, 9H), 1.41 (m, 1H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 169.78, 166.31, 150.27, 140.71, 139.61, 131.32, 131.07, 128.55, 128.53, 127.93, 127.82, 126.57, 125.40, 83.92, 50.98, 42.81, 38.08, 28.05, 25.34, 23.59. **ATR-FTIR (cm^{-1}):** 2980, 1769, 1735, 1369, 1267, 1243, 1148, 1047, 848, 764, 701; **ESI-MS:** calculated $[C_{24}H_{26}N_2O_3 + Na]^+$: 413.1836, found: 413.1830; The product was analyzed by HPLC to determine the enantiomeric excess: 87% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 5.7 min, t_2(minor) = 8.0 min.

(5R,5aS)-tert-butyl 3-oxo-5-phenyl-4,5,5a,6-tetrahydrochromeno[4,3-c][1,2]diazepine-2(3H)-carboxylate (3ap)





Total yield: 50 mg (64%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 8.22 (dd, *J* = 8.0, 1.6 Hz, 1H), 7.22 – 7.17 (m, 1H), 7.16 – 7.10 (m, 1H), 7.08 – 7.00 (m, 2H), 6.97 – 6.87 (m, 3H), 6.43 – 6.36 (m, 1H), 4.22 (dt, *J* = 6.4, 3.2 Hz, 1H), 4.18 – 4.08 (m, 1H), 3.79 – 3.69 (m, 1H), 3.37 (dd, *J* = 8.2, 3.9 Hz, 1H), 2.93 (t, *J* = 12.5 Hz, 1H), 2.59 (dd, *J* = 12.2, 5.9 Hz, 1H), 1.54 (s, 9H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 169.81, 160.51, 157.48, 150.05, 138.37, 133.59, 128.24, 128.01, 127.43, 125.08, 121.52, 118.09, 117.78, 84.15, 65.58, 48.78, 41.95, 37.98, 28.04. **ATR-FTIR (cm^{-1}):** 2981, 1769, 1719, 1482, 1369, 1267, 1245, 1148, 1129, 1020, 831, 761, 734, 700; **ESI-MS:** calculated $[C_{23}H_{24}N_2O_4 + Na]^+$: 415.1628, found: 415.1624; The product was analyzed by HPLC to determine the enantiomeric excess: 85% *ee* (OD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 8.4 min, t_2(minor) = 15.4 min.

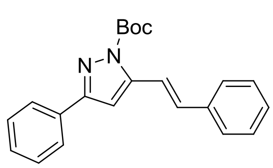
For gram scale synthesis of **3ad**:

To a 50 mL flame-dried Schlenk tube was charged with hydrazone **2d** (1.34g, 5.0 mmol, 1.0 equiv), K_2CO_3 (1.72g, 12.5 mmol, 2.5 equiv). Then, enal **1a** (1.32g, 10 mmol, 2.0 equiv) was added to the mixture. Subsequently, triazolium salt **5c** (184 mmol, 0.5 mmol, 0.1 equiv) in 25 mL THF was slowly added to the mixture. When the reaction was complete, the flask was diluted with CH_2Cl_2 and the solution was transferred to a round flask and concentrated. The residue was purified by flash chromatography (n-pentane/ethyl acetate 4:1) to give 0.92 gram of **3ad** with 51% yield and 99% *ee*.

General procedure for diverse synthesis of 4 via NHC-catalyzed formal [4+1] cycloaddition of in situ-derived azoalkenes and enals.

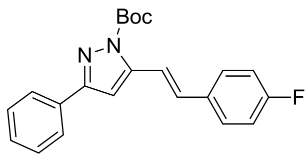
A dried and argon-filled Schlenk flask was charged with Hydrazone **2d** (0.2 mmol, 1.0 equiv) and K_2CO_3 (0.5 mmol). Then, enal **1a** (0.4 mmol) was added quickly to the mixture. Subsequently, triazolium salt **5c** (0.02 mmol, 10 mol%) in 2.5 mL THF was added to the mixture. The mixture was stirred at RT for 16 h. The reaction mixture was opened and *p*-toluenesulfonic acid monohydrate (230 mg, 6 equiv) was added. After 30 min, the reaction was diluted with dichloromethane and transferred to separatory funnel containing saturate sodium hydrogen carbonate solution (15 mL). The organic phase was separated and aqueous phase was extracted with dichloromethane (3 x 15 mL). The organic phases were combined and solvent removed *in vacuo*. After purification by column chromatography on silica gel (Pentane: Ethyl acetate = 15:1) the desired product **4** was obtained.

(*E*)-tert-butyl 3-phenyl-5-styryl-1H-pyrazole-1-carboxylate (4ad)



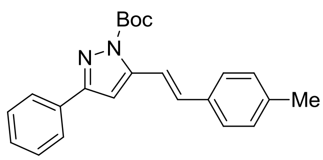
Total yield: 44 mg (64%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.88 – 7.82 (m, 2H), 7.68 (d, *J* = 16.4 Hz, 1H), 7.50 – 7.44 (m, 2H), 7.39 – 7.28 (m, 5H), 7.26 – 7.21 (m, 1H), 7.06 (d, *J* = 16.4 Hz, 1H), 6.88 (s, 1H), 1.64 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 153.64, 146.44, 136.44, 133.53, 131.90, 128.95, 128.81, 128.62, 128.54, 126.92, 126.38, 117.30, 104.26, 85.41, 28.06. **ATR-FTIR (cm^{-1}):** 2979, 1742, 1555, 1439, 1352, 1311, 1155, 1104, 1078, 948, 850, 769, 693; **ESI-MS:** calculated $[C_{22}H_{22}N_2O_2 + Na]^+$: 369.1573, found: 369.1566;

(*E*)-tert-butyl 5-(4-fluorostyryl)-3-phenyl-1H-pyrazole-1-carboxylate (4bd)



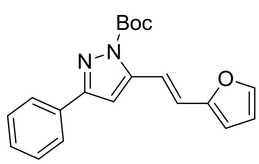
Total yield: 41 mg (57%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.74 – 7.60 (m, 3H), 7.49 – 7.43 (m, 2H), 7.35 – 7.28 (m, 2H), 7.27 – 7.20 (m, 2H), 7.12 (d, *J* = 7.6 Hz, 1H), 7.05 (d, *J* = 16.4 Hz, 1H), 6.87 (d, *J* = 0.6 Hz, 1H), 2.34 (s, 3H), 1.64 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 153.63, 149.02, 146.33, 132.65, 132.26, 131.85, 128.99, 128.63, 128.58, 128.50, 126.36, 117.11, 115.95, 115.73, 104.20, 85.44, 28.04. **^{19}F NMR (282 MHz, CDCl$_3$)** δ -112.6. **ATR-FTIR (cm^{-1}):** 2982, 1741, 1509, 1351, 1325, 1231, 1155, 1103, 1078, 948, 822, 769, 694; **ESI-MS:** calculated [$C_{22}H_{21}N_2O_2F$ + Na]$^+$: 387.1479, found: 387.1473;

(*E*)-tert-butyl 5-(4-methylstyryl)-3-phenyl-1H-pyrazole-1-carboxylate (4ed)



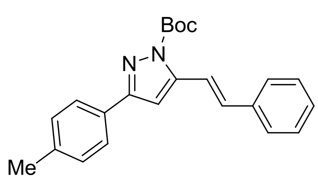
Total yield: 37 mg (52%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.88 – 7.82 (m, 2H), 7.63 (d, *J* = 16.5 Hz, 1H), 7.38 – 7.29 (m, 5H), 7.11 (d, *J* = 7.9 Hz, 2H), 7.03 (d, *J* = 16.4 Hz, 1H), 6.86 (d, *J* = 0.6 Hz, 1H), 2.30 (s, 3H), 1.63 (s, 9H).**^{13}C NMR (101 MHz, CDCl$_3$)** δ 153.63, 149.00, 146.66, 138.64, 133.68, 133.54, 131.94, 129.86, 129.54, 128.92, 128.61, 126.86, 126.38, 116.27, 104.03, 85.34, 28.06, 21.36. **ATR-FTIR (cm^{-1}):** 2980, 1741, 1681, 1554, 1460, 1440, 1351, 1311, 1154, 1102, 1078, 948, 769, 694; **ESI-MS:** calculated [$C_{23}H_{24}N_2O_2$ + Na]$^+$: 383.1730, found: 383.1728;

(*E*)-tert-butyl 5-(2-(furan-2-yl)vinyl)-3-phenyl-1H-pyrazole-1-carboxylate (4gd)



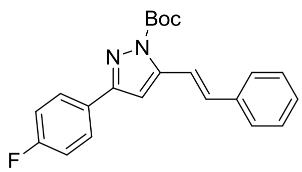
Total yield: 48 mg (72%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.88 – 7.82 (m, 2H), 7.72 – 7.65 (m, 1H), 7.50 – 7.44 (m, 2H), 7.39 – 7.28 (m, 5H), 7.26 – 7.21 (m, 1H), 7.07 (t, *J* = 11.5 Hz, 1H), 6.88 (s, 1H), 1.64 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 153.62, 152.40, 148.86, 146.07, 143.14, 131.88, 128.94, 128.61, 126.36, 120.82, 115.49, 111.86, 110.52, 103.83, 85.53, 28.01. **ATR-FTIR (cm^{-1}):** 2983, 1740, 1459, 1347, 1309, 1242, 1152, 1102, 1078, 948, 768, 730, 693; **ESI-MS:** calculated [$C_{20}H_{20}N_2O_3$ + Na]$^+$: 359.1366, found: 359.1362;

(*E*)-tert-butyl 5-styryl-3-(p-tolyl)-1H-pyrazole-1-carboxylate (4ae)



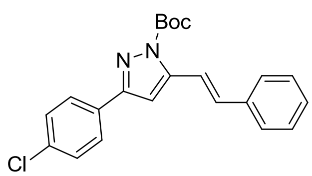
Total yield: 49 mg (68%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.74 (d, *J* = 8.1 Hz, 2H), 7.67 (d, *J* = 16.4 Hz, 1H), 7.48 – 7.43 (m, 2H), 7.31 (dd, *J* = 10.2, 4.6 Hz, 2H), 7.25 – 7.21 (m, 1H), 7.16 (d, *J* = 7.9 Hz, 2H), 7.04 (d, *J* = 16.4 Hz, 1H), 6.85 (d, *J* = 0.4 Hz, 1H), 2.30 (s, 3H), 1.63 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 153.70, 149.00, 146.33, 138.90, 136.48, 133.43, 129.32, 129.06, 128.81, 128.51, 126.91, 126.27, 117.36, 104.20, 85.33, 28.07, 21.39. **ATR-FTIR (cm^{-1}):** 2982, 1741, 1440, 1333, 1311, 1239, 1155, 1102, 1067, 948, 799, 749, 693; **ESI-MS:** calculated $[C_{23}H_{24}N_2O_2 + Na]^+$: 383.1730, found: 383.1723;

(*E*)-tert-butyl 3-(4-fluorophenyl)-5-styryl-1H-pyrazole-1-carboxylate (4ag)



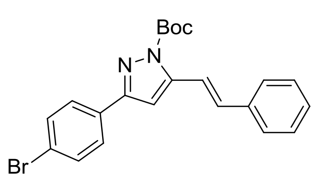
Total yield: 45 mg (62%); **^{1}H NMR (300 MHz, CDCl$_3$)** δ 7.86 – 7.79 (m, 2H), 7.67 (d, *J* = 16.4 Hz, 1H), 7.50 – 7.43 (m, 2H), 7.36 – 7.28 (m, 2H), 7.27 – 7.23 (m, 1H), 7.09 – 7.01 (m, 3H), 6.83 (s, 1H), 1.63 (s, 9H). **^{13}C NMR (75 MHz, CDCl$_3$)** δ 152.71, 148.89, 146.59, 136.35, 133.69, 128.83, 128.61, 128.23, 128.12, 126.93, 117.15, 115.76, 115.47, 104.03, 85.53, 28.04. **^{19}F NMR (282 MHz, CDCl$_3$)** δ -112.5. **ATR-FTIR (cm^{-1}):** 2982, 1734, 1608, 1520, 1438, 1333, 1234, 1156, 1103, 1067, 842, 750, 693; **ESI-MS:** calculated $[C_{22}H_{21}N_2O_2F + Na]^+$: 387.1479, found: 387.1477;

(*E*)-tert-butyl 3-(4-chlorophenyl)-5-styryl-1H-pyrazole-1-carboxylate (4ah)



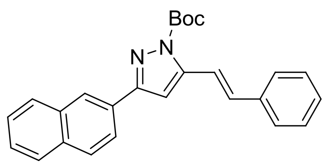
Total yield: 46 mg (61%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.76 – 7.70 (m, 2H), 7.66 (d, *J* = 16.7 Hz, 1H), 7.51 – 7.43 (m, 4H), 7.35 – 7.28 (m, 2H), 7.24 (m, 1H), 7.05 (d, *J* = 16.4 Hz, 1H), 6.84 (d, *J* = 0.4 Hz, 1H), 1.63 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 152.52, 148.84, 146.65, 136.34, 134.82, 133.78, 130.44, 128.85, 128.64, 127.64, 126.94, 117.10, 104.07, 85.63, 28.04. **ATR-FTIR (cm^{-1}):** 2981, 1743, 1432, 1331, 1310, 1154, 1102, 1091, 1066, 948, 837, 799, 750, 692; **ESI-MS:** calculated $[C_{22}H_{21}N_2O_2Cl + Na]^+$: 403.1184, found: 403.1177;

(*E*)-tert-butyl 3-(4-bromophenyl)-5-styryl-1H-pyrazole-1-carboxylate (4ai)



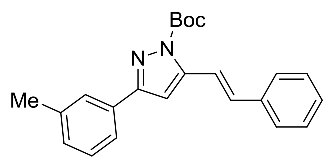
Total yield: 46 mg (55%); **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.76 – 7.70 (m, 2H), 7.66 (d, *J* = 16.7 Hz, 1H), 7.51 – 7.43 (m, 4H), 7.35 – 7.28 (m, 2H), 7.24 (m, 1H), 7.05 (d, *J* = 16.4 Hz, 1H), 6.84 (d, *J* = 0.4 Hz, 1H), 1.63 (s, 9H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 152.55, 148.82, 146.66, 136.33, 133.81, 131.80, 130.89, 128.84, 128.65, 127.91, 126.94, 123.09, 117.08, 104.04, 85.65, 28.04. **ATR-FTIR (cm^{-1}):** 2982, 1744, 1431, 1331, 1310, 1156, 1102, 1072, 1011, 948, 800, 750, 692; **ESI-MS:** calculated $[C_{22}H_{21}N_2O_2Br + Na]^+$: 449.0659, found: 449.0656;

(*E*)-tert-butyl 3-(naphthalen-2-yl)-5-styryl-1H-pyrazole-1-carboxylate (4ak)



Total yield: 46 mg (58%); **^{1}H NMR (400 MHz, $CDCl_3$)** δ 8.29 (s, 1H), 8.03 (dd, J = 8.5, 1.7 Hz, 1H), 7.83 (dd, J = 8.8, 3.8 Hz, 2H), 7.80 – 7.75 (m, 1H), 7.73 – 7.67 (m, 1H), 7.50 – 7.46 (m, 2H), 7.45 – 7.40 (m, 2H), 7.32 (dd, J = 10.2, 4.6 Hz, 2H), 7.27 – 7.22 (m, 1H), 7.10 (d, J = 16.4 Hz, 1H), 7.02 (s, 1H), 1.66 (s, 9H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 153.61, 148.97, 146.55, 136.45, 133.64, 133.36, 129.31, 128.84, 128.58, 128.39, 128.34, 127.79, 126.94, 126.41, 126.35, 125.61, 124.14, 117.30, 104.47, 85.54, 28.09. **ATR-FTIR (cm^{-1}):** 3057, 2982, 1741, 1367, 1321, 1155, 1099, 947, 802, 749, 692; **ESI-MS:** calculated $[C_{26}H_{24}N_2O_2 + Na]^+$: 419.1730, found: 419.1717;

(*E*)-tert-butyl 5-styryl-3-(m-tolyl)-1H-pyrazole-1-carboxylate (4am)

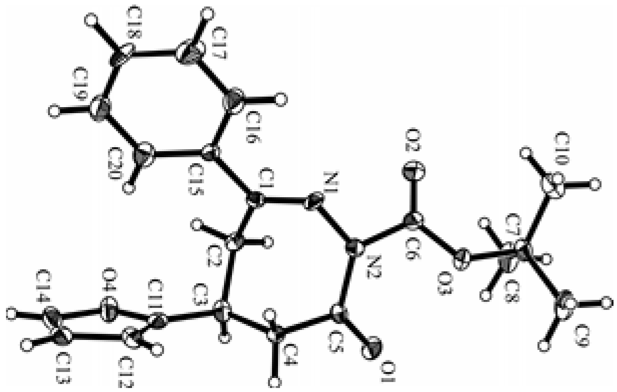


Total yield: 48 mg (67%); **^{1}H NMR (300 MHz, $CDCl_3$)** δ 7.74 – 7.60 (m, 3H), 7.49 – 7.43 (m, 2H), 7.35 – 7.28 (m, 2H), 7.27 – 7.20 (m, 2H), 7.12 (d, J = 7.6 Hz, 1H), 7.05 (d, J = 16.4 Hz, 1H), 6.87 (d, J = 0.6 Hz, 1H), 2.34 (s, 3H), 1.64 (s, 9H). **^{13}C NMR (75 MHz, $CDCl_3$)** δ 153.78, 148.97, 146.33, 138.28, 136.45, 133.47, 131.71, 129.75, 128.82, 128.53, 128.50, 126.98, 126.91, 123.51, 117.32, 104.35, 85.42, 28.06, 21.43. **ATR-FTIR (cm^{-1}):** 2982, 1742, 1555, 1333, 1311, 1239, 1155, 1104, 1076, 963, 787, 693; **ESI-MS:** calculated $[C_{23}H_{24}N_2O_2 + Na]^+$: 383.1730, found: 383.1725;

4. X-ray Crystallography data

X-Ray diffraction: Data sets were collected with a D8 Venture Dual Source 100 CMOS diffractometer. Programs used: data collection: APEX2 V2014.5-0 (Bruker AXS Inc., 2014);[2a] cell refinement: SAINT V8.34A (Bruker AXS Inc., 2013);[2a] data reduction: SAINT V8.34A (Bruker AXS Inc., 2013);[2a] absorption correction, SADABS V2014/2 (Bruker AXS Inc., 2014);[2a] structure solution SHELXT-2014 (Sheldrick, 2014);[2b] structure refinement SHELXL-2014 (Sheldrick, 2014)[2b] and graphics, XP (Bruker AXS Inc., 2014).[2b] *R*-values are given for observed reflections, and wR^2 values are given for all reflections.

X-ray crystal structure analysis of 3gd: formula $C_{20}H_{22}N_2O_4$, M = 354.39, colourless crystal, 0.191 x 0.178 x 0.067 mm, a = 5.8916(3), b = 11.8596(5), c = 25.8111(11) Å, V = 1801.8(1) Å^3, ρ_{calc} = 1.306 gcm^{-3}, μ = 0.749 mm^{-1}, empirical absorption correction (0.870 ≤ T ≤ 0.952), Z = 4, monoclinic, space group $P2_1$ (No. 4), λ = 1.54178 Å, T = 100(2) K, ω and φ scans, 15935 reflections collected, 5175 independent (R_{int} = 0.087) and 4069 observed reflections [I>2σ(I)], 472 refined parameters, R = 0.054, wR^2 = 0.122, max. (min.) residual electron density 0.33 (-0.20) e.Å^{-3}, hydrogen atoms calculated and refined as riding atoms. Flack parameter: 0.0(2).

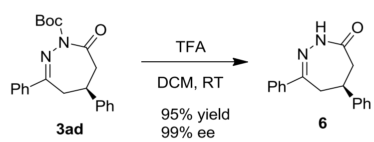


Crystal structure of compound **3gd**.

Only one molecule from two found in the asymmetric unit is shown.

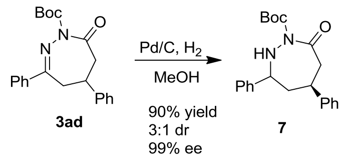
(Thermals ellipsoids are shown with 50% probability.)

5. Synthetic Transformation of 3ad



To a cooled (0 °C) solution of **3ad** (36.4 mg, 0.1 mmol) in CH_2Cl_2 (6 mL), 4.0 equiv of TFA (31 μL, 0.4 mmol) was added. The solution was then allowed to warm to room temperature, and then stirred for 4 h. After 4 h, sat. $NaHCO_3$ solution was added and the organic layer was extracted with CH_2Cl_2, dried over Na_2SO_4. After removing solvents, the residue was purified by column chromatography to give the product **6** in 95% yield (25 mg).

^{1}H NMR (400 MHz, CDCl$_3$) δ 8.52 (s, 1H), 7.71 – 7.59 (m, 2H), 7.41 – 7.31 (m, 3H), 7.29 – 7.23 (m, 4H), 7.23 – 7.18 (m, 1H), 3.74 (m, 1H), 3.18 (dd, J = 13.2, 6.7 Hz, 1H), 3.03 (dd, J = 13.2, 9.7 Hz, 1H), 2.76 (dd, J = 13.4, 8.0 Hz, 1H), 2.66 (dd, J = 13.4, 5.2 Hz, 1H). **^{13}C NMR (101 MHz, CDCl$_3$)** δ 171.80, 166.80, 143.50, 136.18, 130.62, 128.97, 128.74, 127.35, 126.73, 126.63, 45.48, 39.61, 36.09. **ATR-FTIR (cm^{-1}):** 3211, 3084, 2914, 1651, 1447, 1341, 1305, 1159, 1021, 755, 693; **ESI-MS:** calculated $[C_{17}H_{16}N_2O + Na]^+$: 287.1155, found: 287.1152; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (AD-H, hexane/*i*-PrOH = 70/30, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 7.5 min, t_2(minor) = 12.1 min.



A suspension of Pd/C (20 mg) and **3ad** (36.4 mg, 0.1 mmol) in MeOH (2.5 mL) was stirred at RT under 1 atm hydrogen atmosphere. After being stirred overnight, the mixture was filtrated through a pad of Celite and the filtration was concentrated in vacuo, the residue was purified by column chromatography on silica gel to afford the desired the product **7** in 90% yield (33 mg, d.r. = 3:1, *ee* = 99%).

Major isomer: **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.34 – 7.12 (m, 10H), 5.07 (s, 1H), 3.76 (m, 2H), 3.11 – 3.02 (m, 1H), 2.60 (d, *J* = 12.6 Hz, 1H), 2.21 – 2.10 (m, 1H), 2.03 (d, *J* = 13.6 Hz, 1H), 1.46 (s, 9H). **^{13}C NMR (101 MHz, $CDCl_3$)** δ 172.68, 172.52, 150.93, 150.60, 145.13, 139.93, 127.84, 127.71, 125.79, 125.45, 83.54, 65.46, 58.66, 44.24, 39.96, 27.03. **ATR-FTIR (cm^{-1}):** 2982, 1722, 1493, 1369, 1239, 1147, 1098, 1030, 734, 699; **ESI-MS:** calculated $[C_{22}H_{26}N_2O_3 + Na]^+$: 389.1836, found: 389.1828; The product was analyzed by HPLC to determine the enantiomeric excess: 99% *ee* (AD-H, hexane/*i*-PrOH = 85/15, detector: 254 nm, flow rate: 1 mL/min), t_1(major) = 6.2 min, t_2(minor) = 6.7 min.

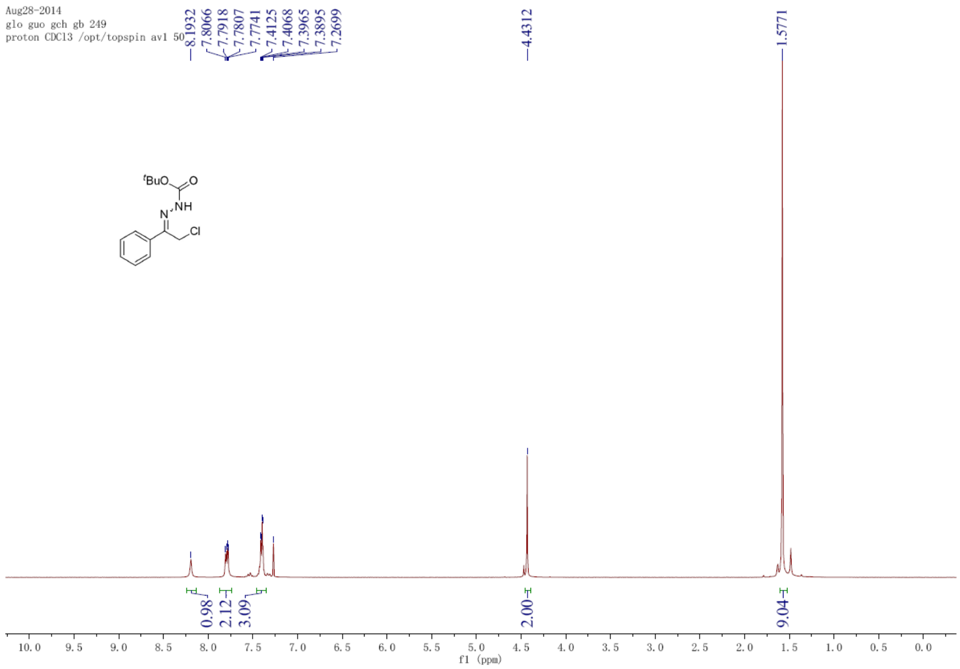
6 References

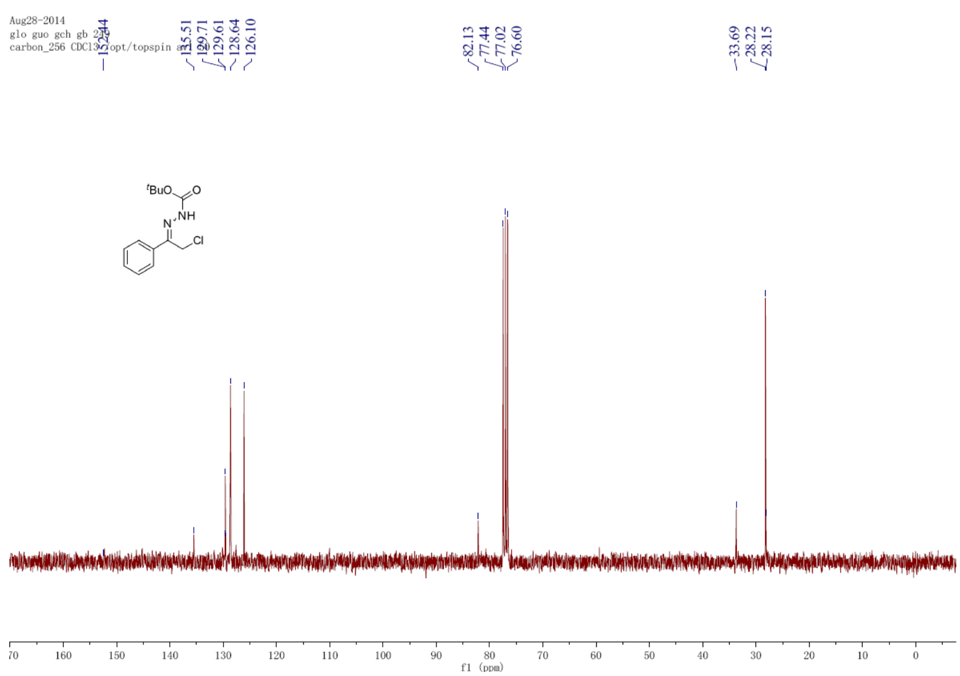
1. (a) Chen, J.-R.; Dong, W.-R.; Candy, M.; Pan, F.-F.; Jörres, M.; Bolm, C. *J. Am. Chem.Soc.* **2012**, *134*, 6924; (b) South, M. S.; Jakuboski, T. L.; Westmeyer, M. D.; Dukesherer, D. R. *J. Org. Chem.* **1996**, *61*, 8921.

2. (a) Bruker *APEX2*, *SAINT* and *SADABS* 2013. Bruker AXS Inc., Madison, Wisconsin, USA; (b). SHELXT und SHELXL Sheldrick, G. M. *Acta Cryst.* **2008**. A***64***, 112–122.

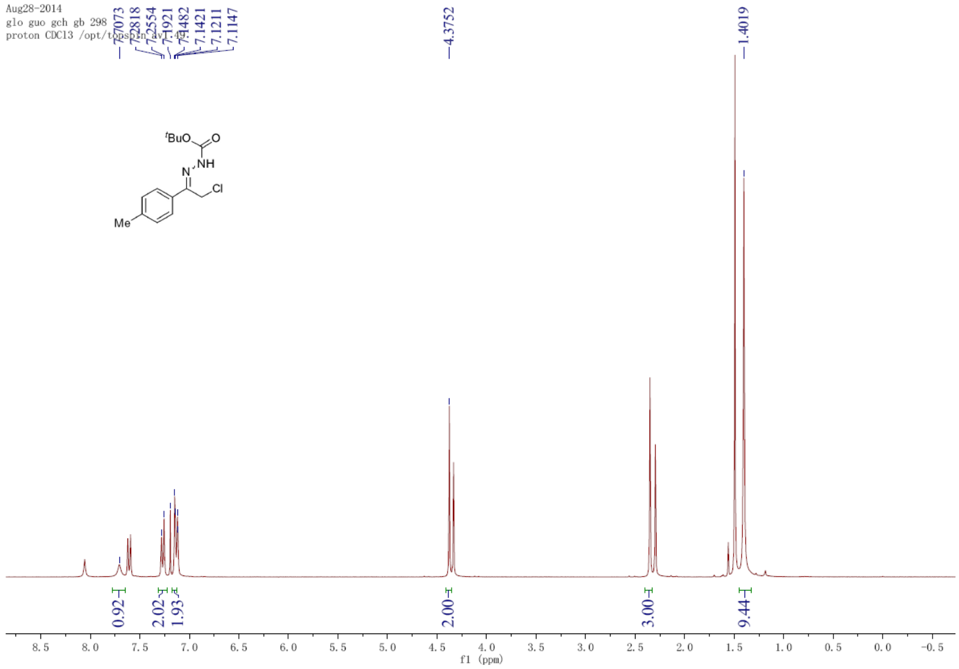
7 NMR spectra

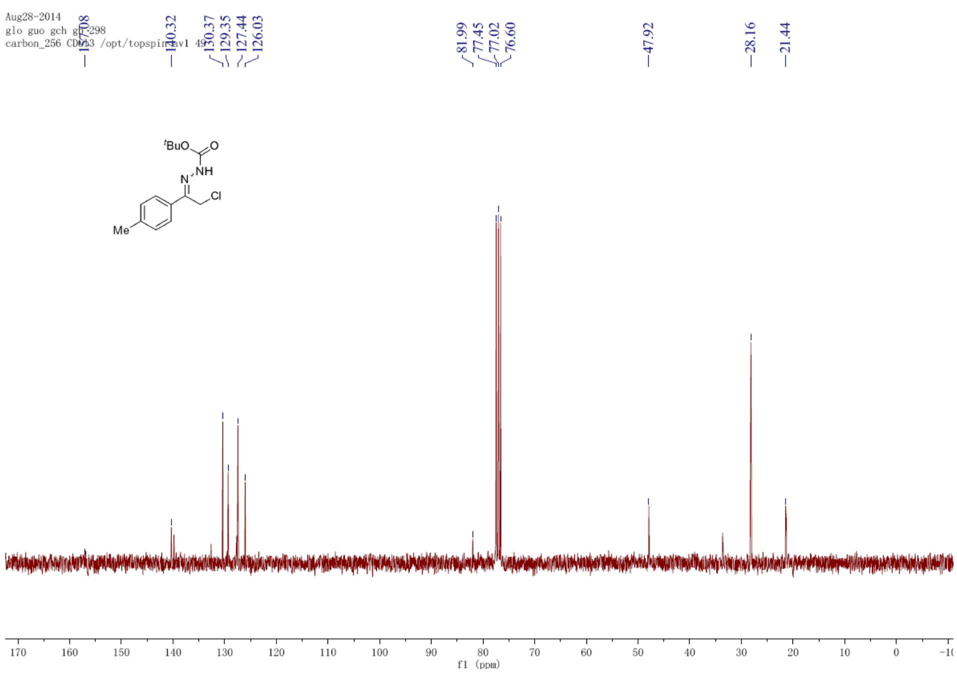
tert-butyl 2-(2-chloro-1-phenylethylidene)hydrazinecarboxylate (2d)



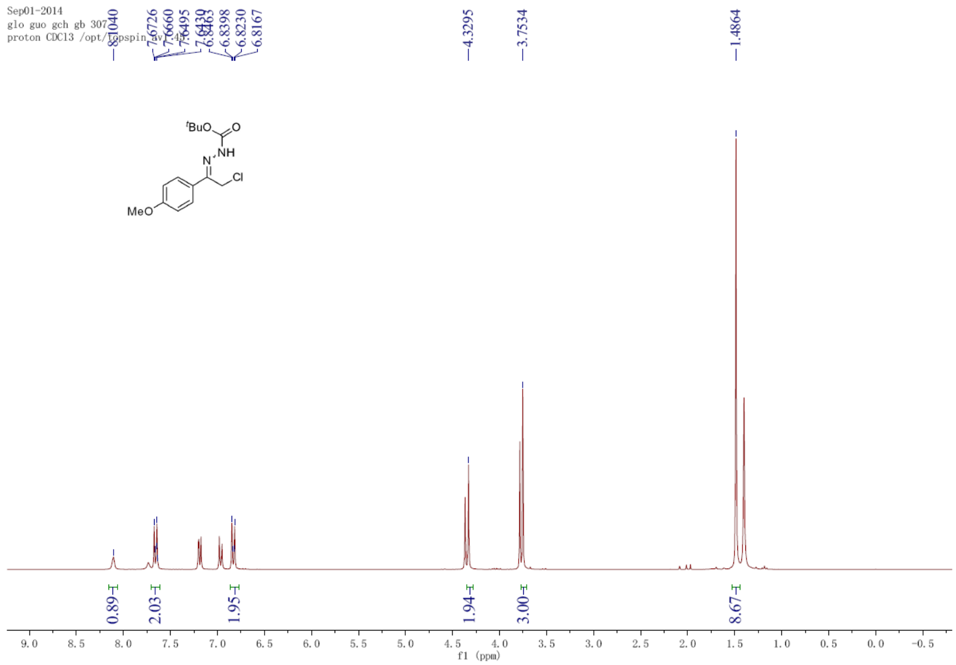


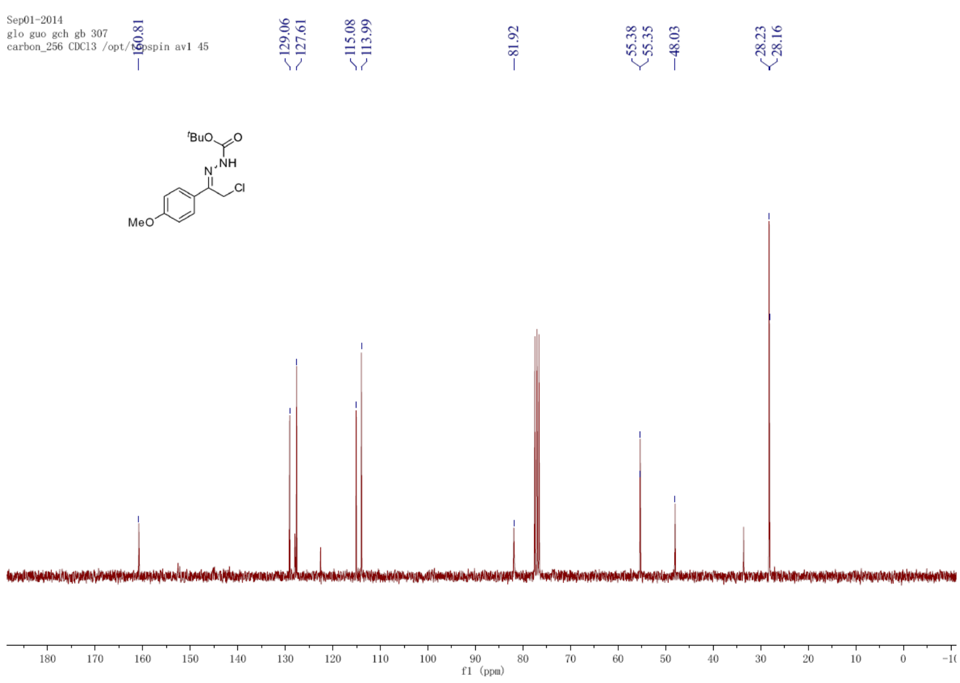
tert-butyl 2-(2-chloro-1-(p-tolyl)ethylidene)hydrazinecarboxylate (2e)



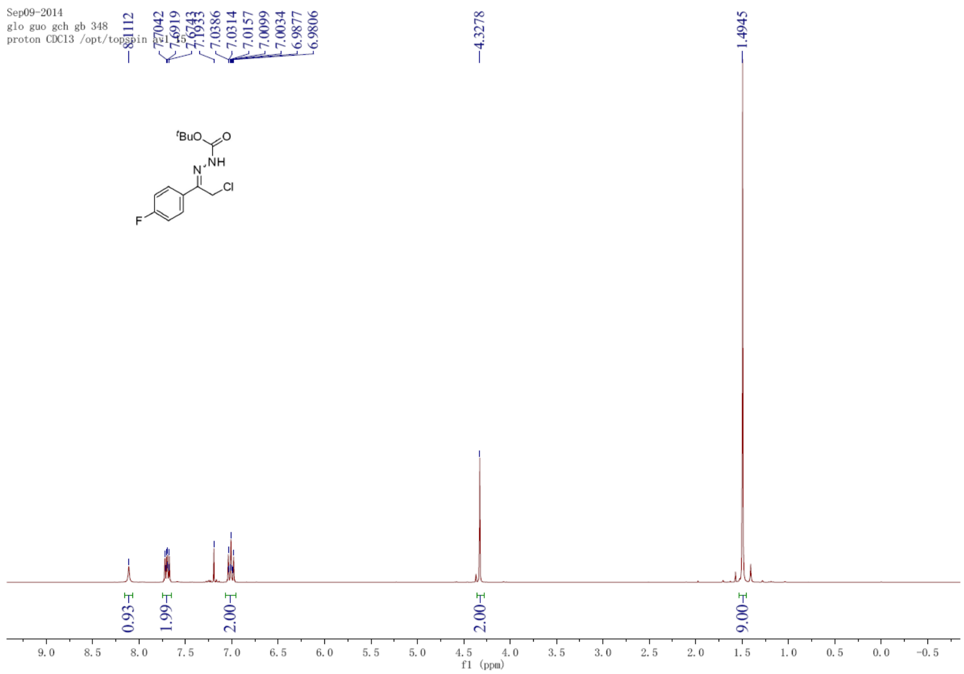


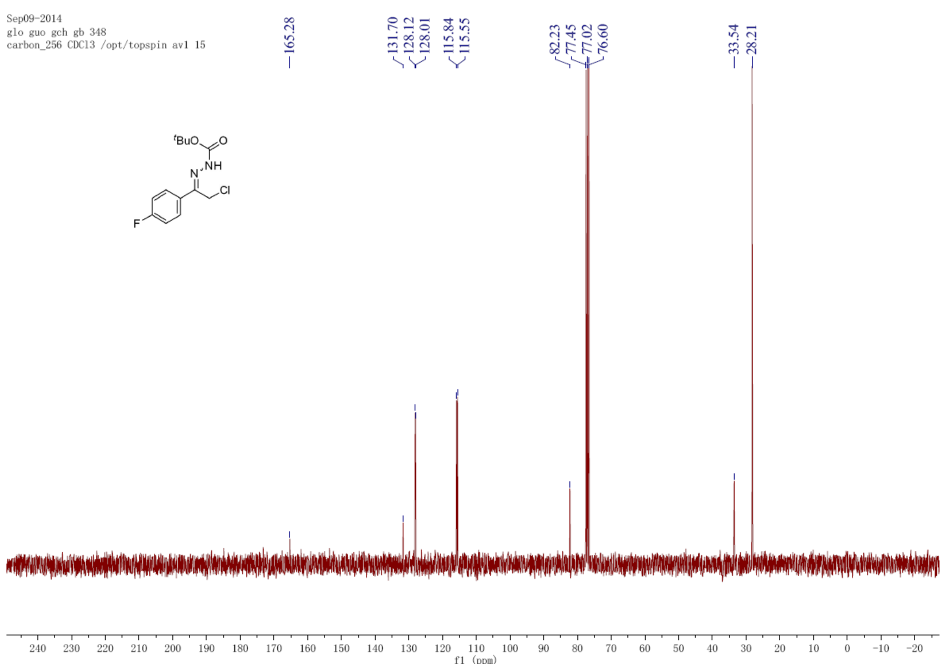
tert-butyl 2-(2-chloro-1-(4-methoxyphenyl)ethylidene)hydrazinecarboxylate (2f)



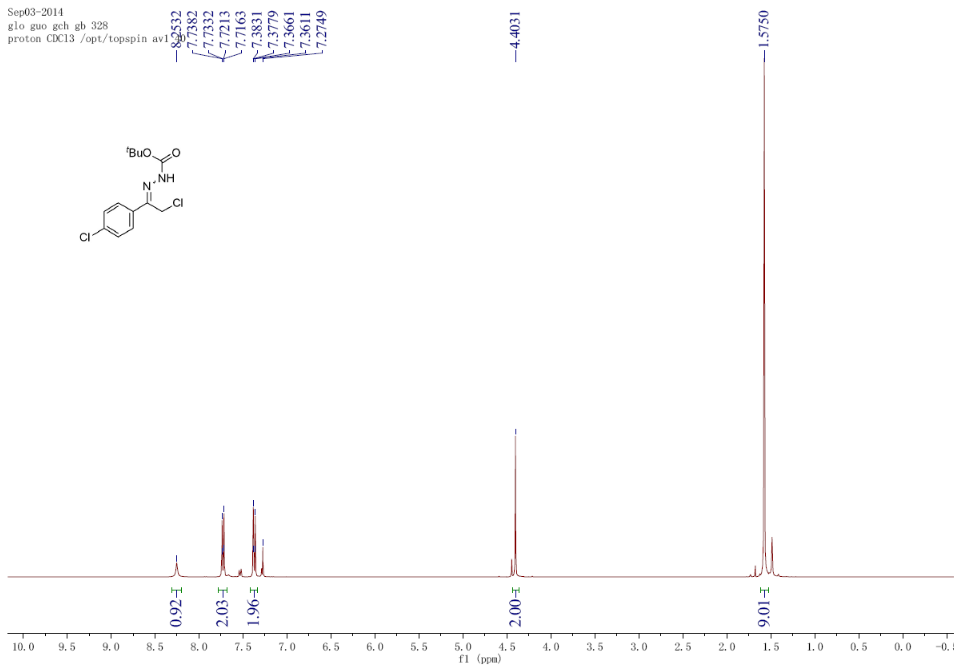


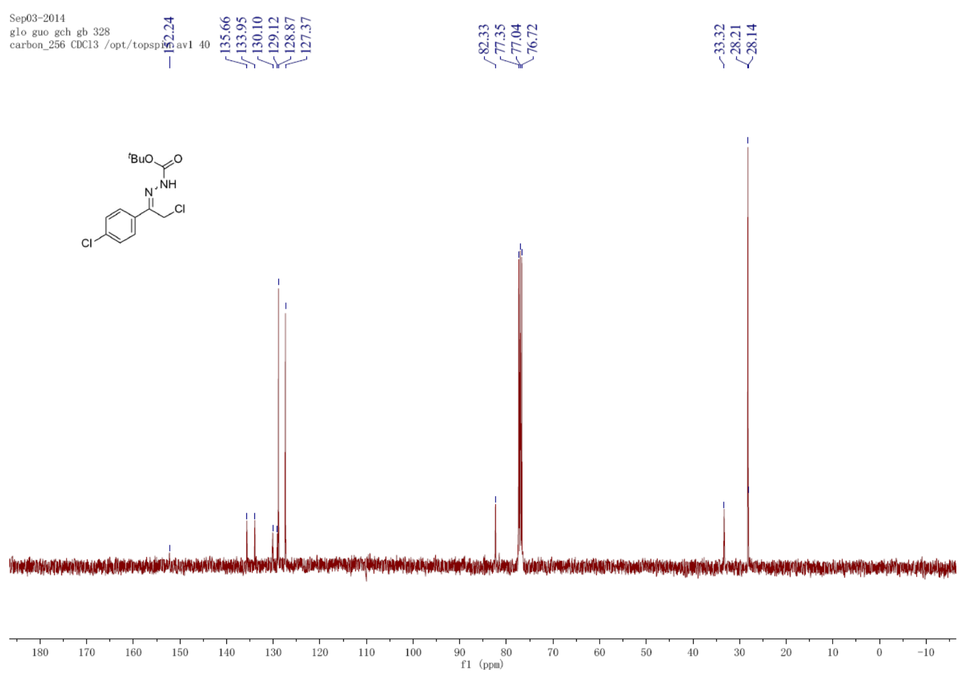
tert-butyl 2-(2-chloro-1-(4-fluorophenyl)ethylidene)hydrazinecarboxylate (2g)



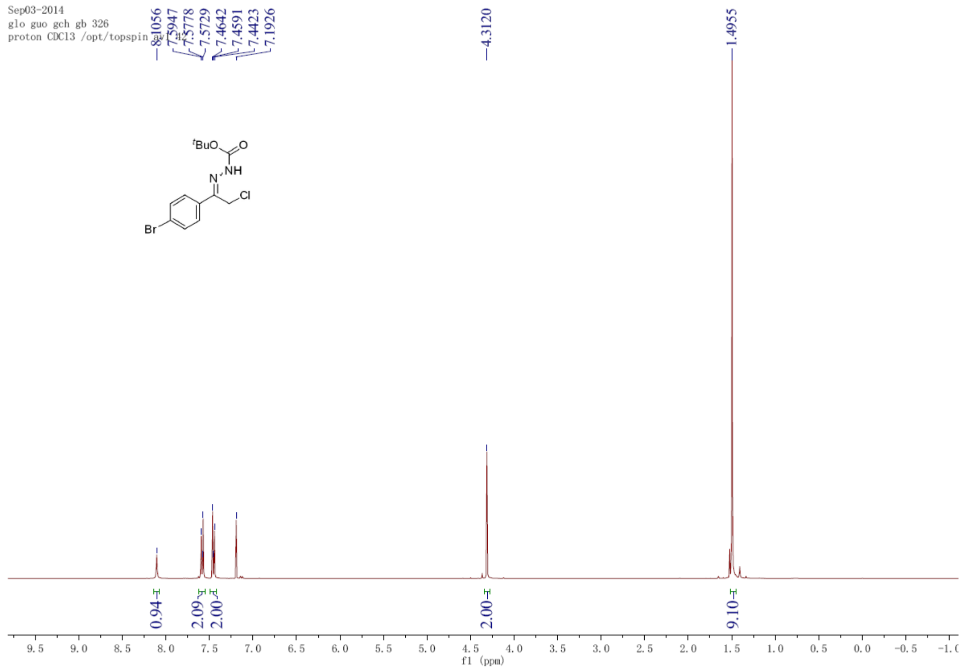


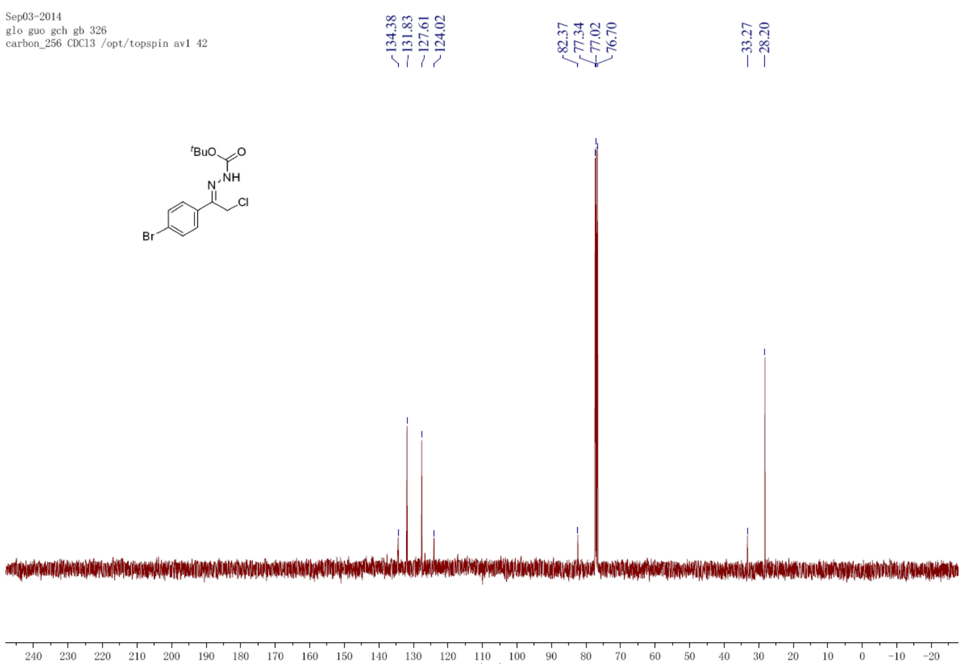
tert-butyl 2-(2-chloro-1-(4-chlorophenyl)ethylidene)hydrazinecarboxylate (2h)



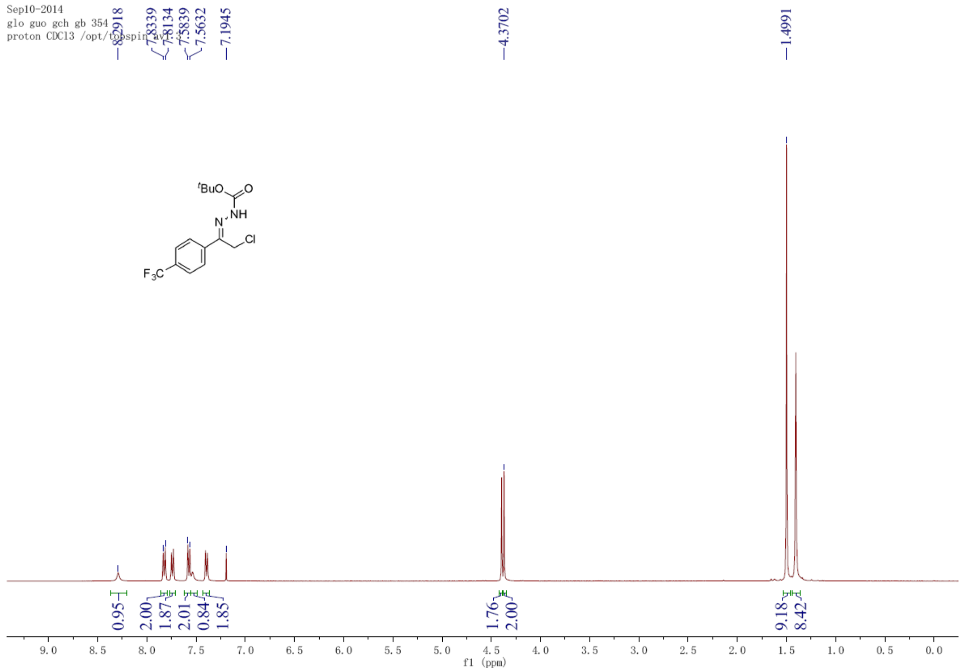


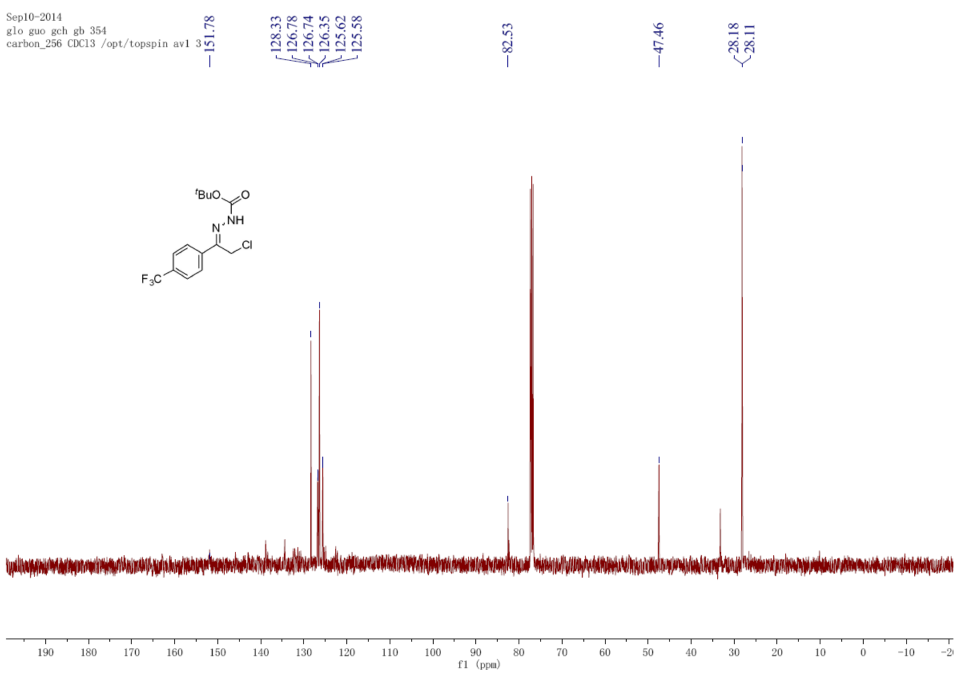
tert-butyl 2-(1-(4-bromophenyl)-2-chloroethylidene)hydrazinecarboxylate (2i)



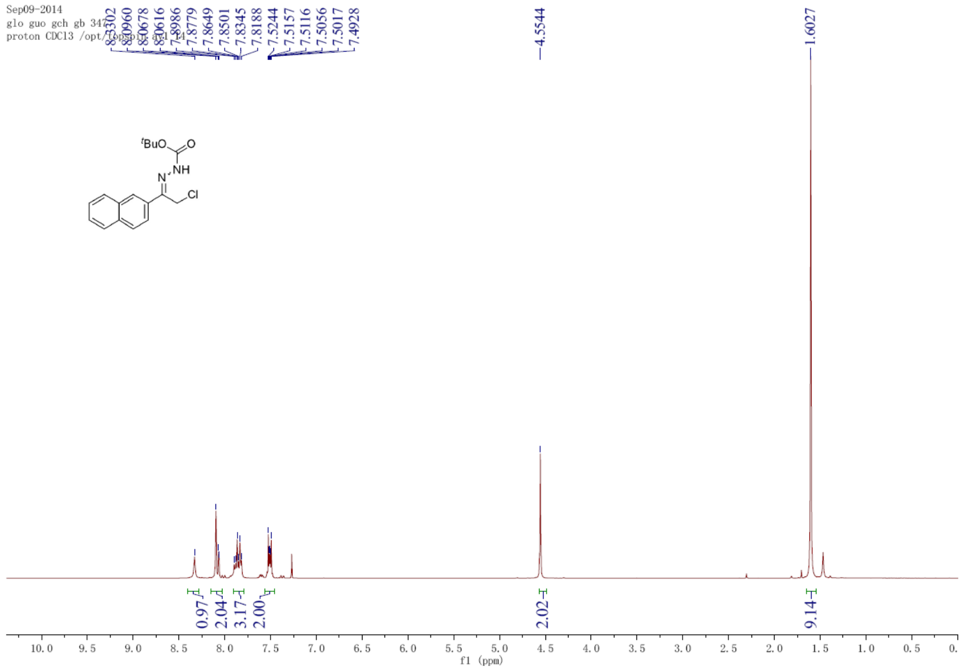


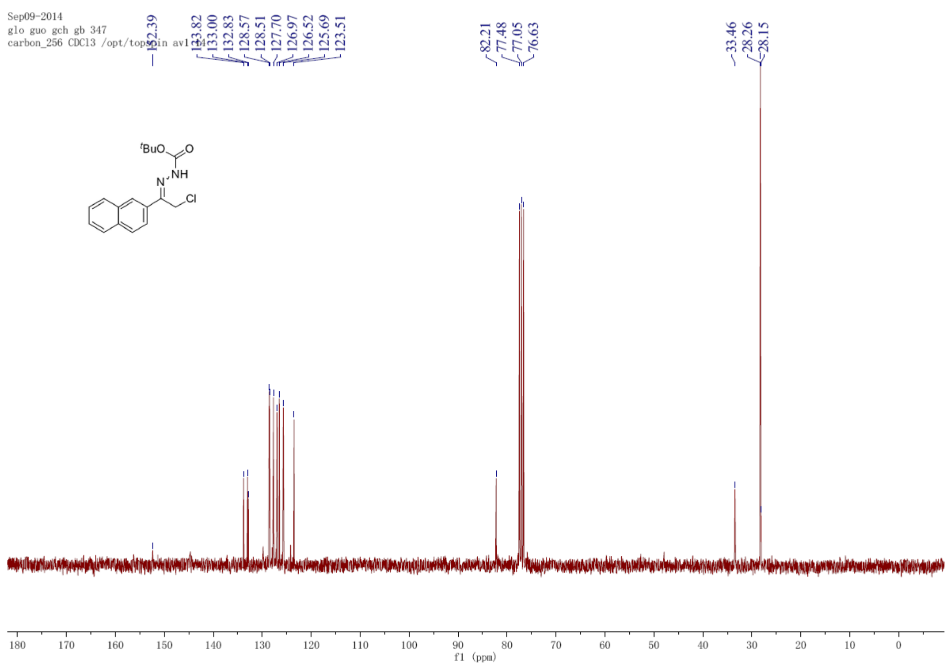
tert-butyl 2-(2-chloro-1-(4-(trifluoromethyl)phenyl)ethylidene)hydrazinecarboxylate (2j)



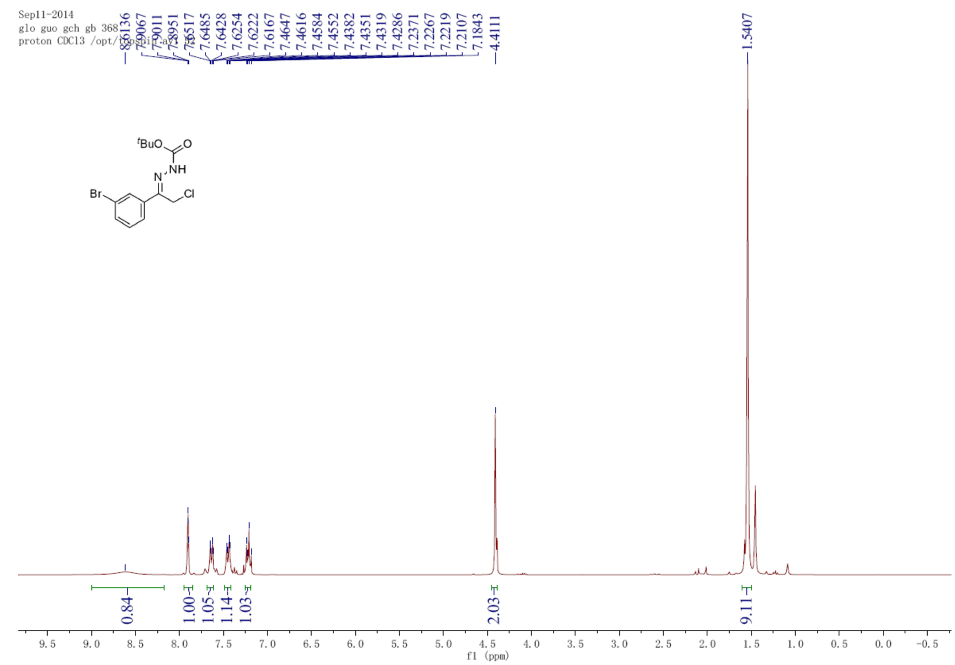


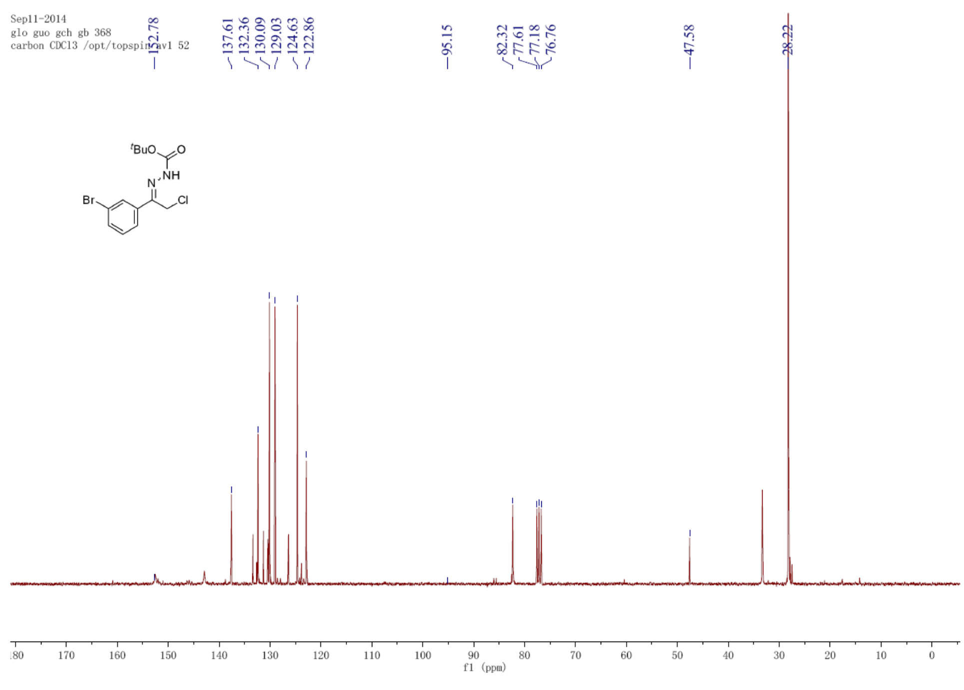
tert-butyl 2-(2-chloro-1-(naphthalen-2-yl)ethylidene)hydrazinecarboxylate (2k)



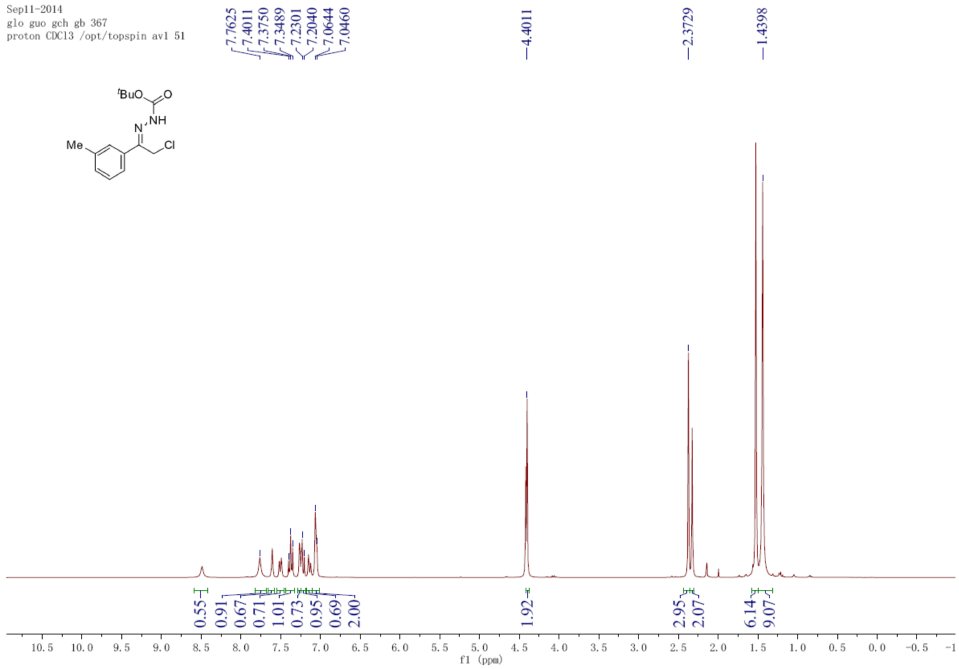


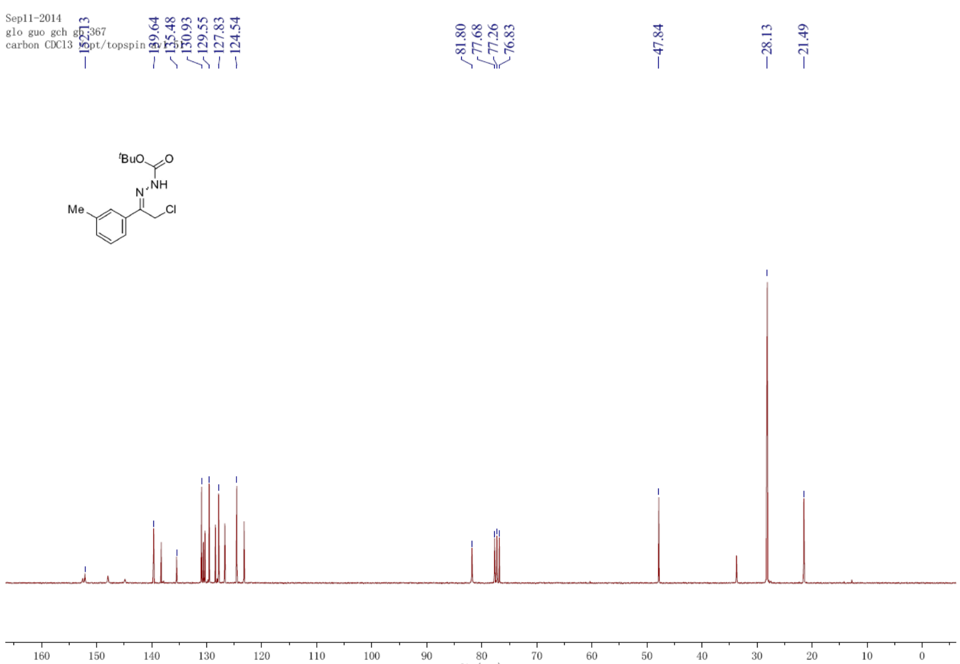
tert-butyl 2-(1-(3-bromophenyl)-2-chloroethylidene)hydrazinecarboxylate (2l)



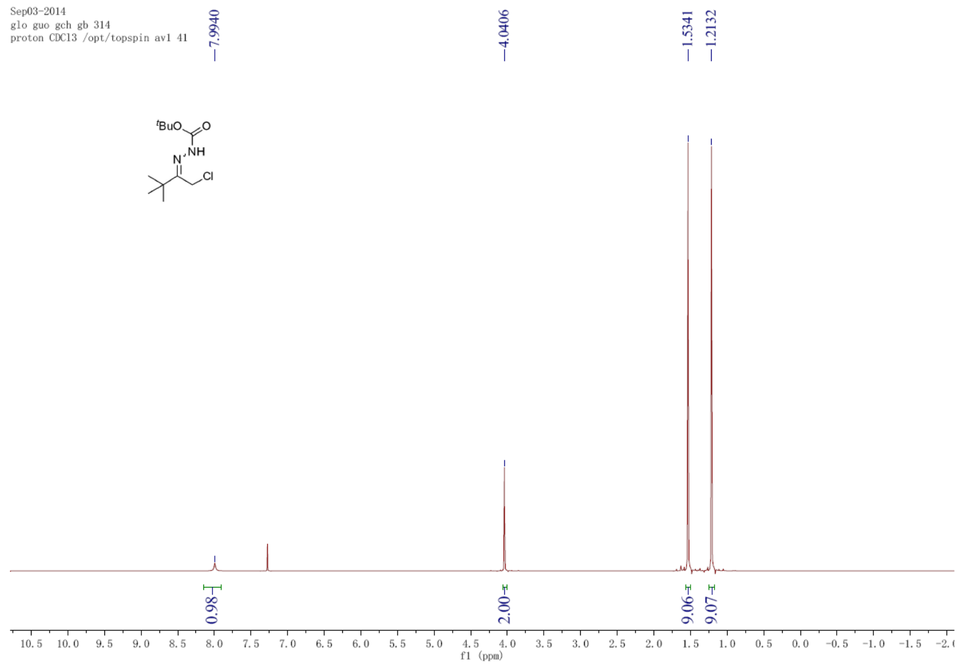


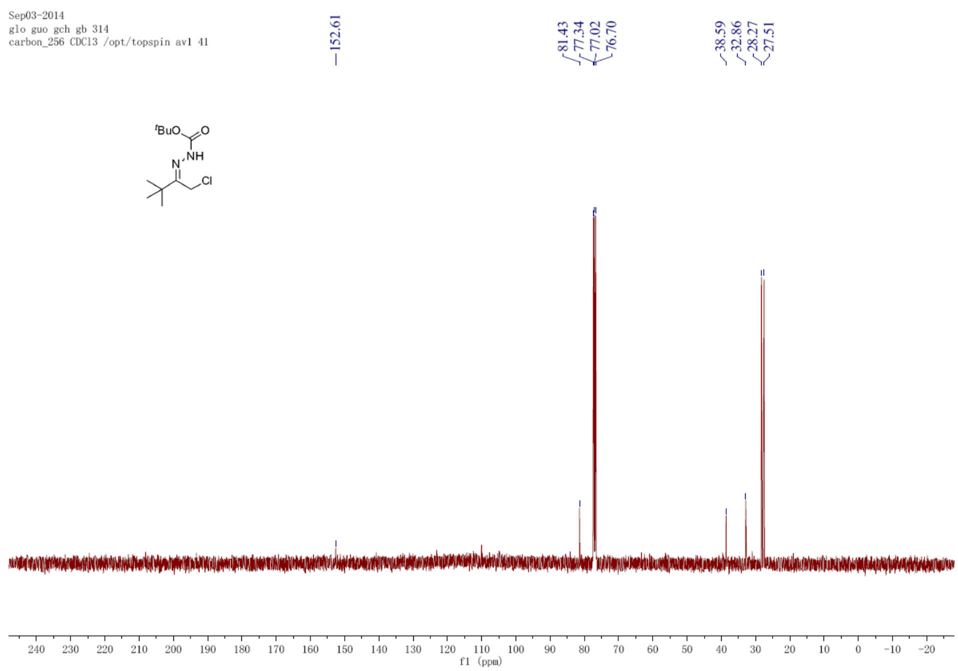
tert-butyl 2-(2-chloro-1-(m-tolyl)ethylidene)hydrazinecarboxylate (2m)



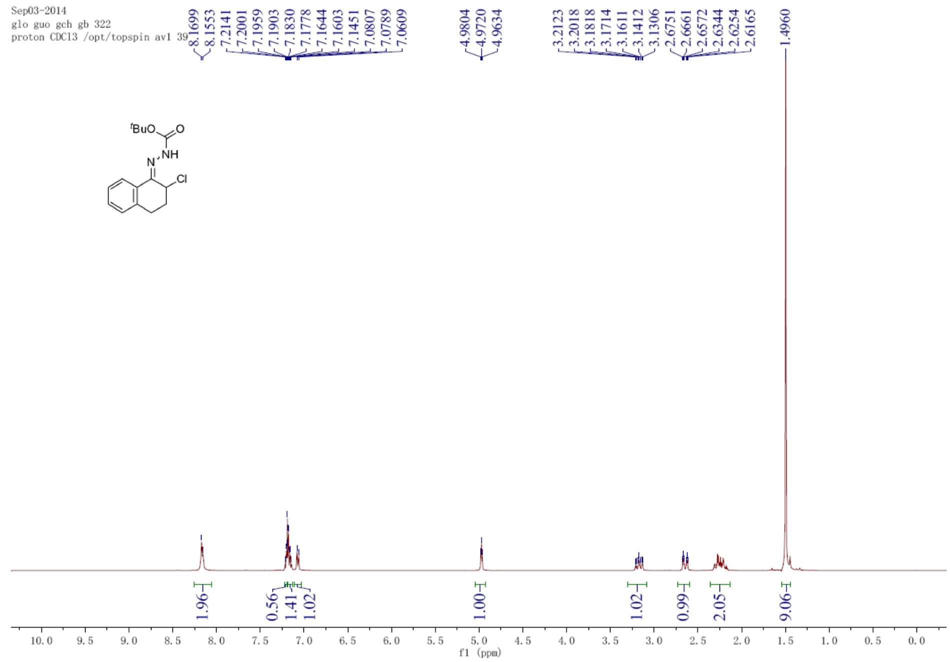


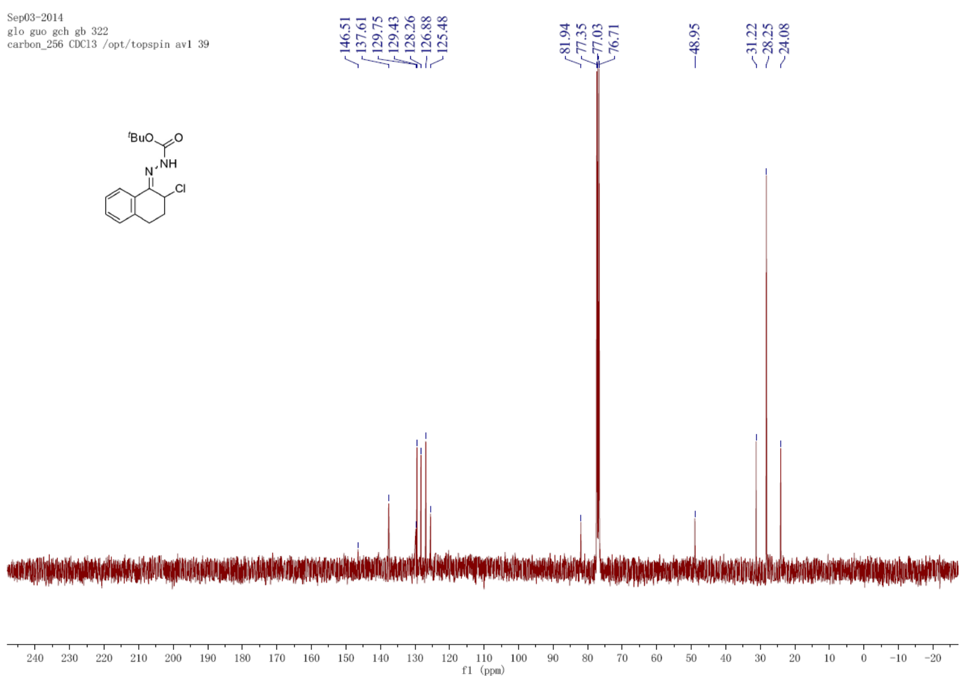
tert-butyl 2-(1-chloro-3,3-dimethylbutan-2-ylidene)hydrazinecarboxylate (2n)



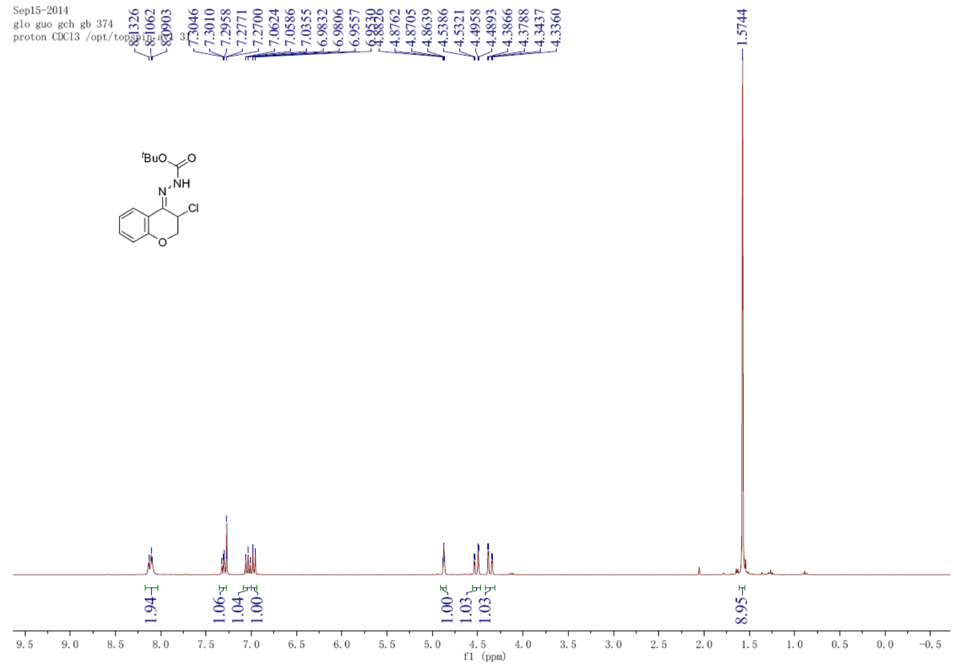


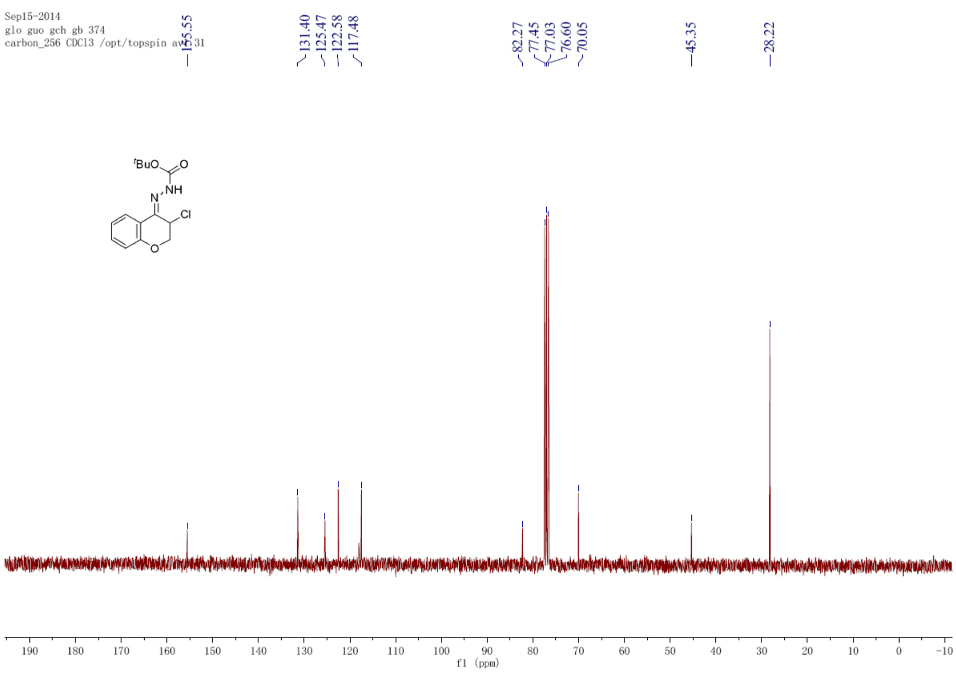
tert-butyl 2-(2-chloro-3,4-dihydronaphthalen-1(2H)-ylidene)hydrazinecarboxylate (2o)



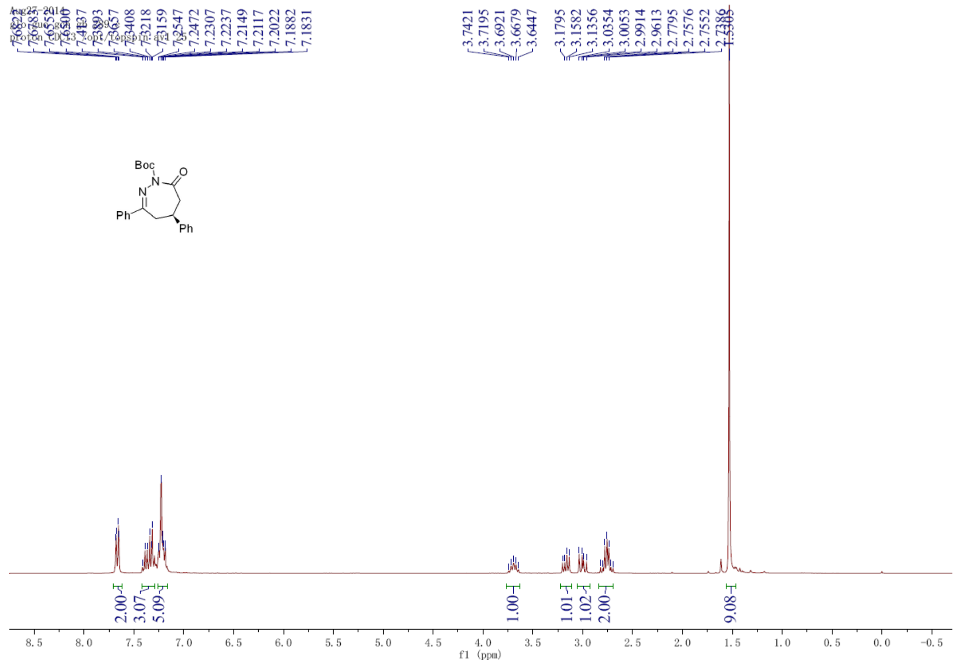


tert-butyl 2-(3-chlorochroman-4-ylidene)hydrazinecarboxylate (2p)

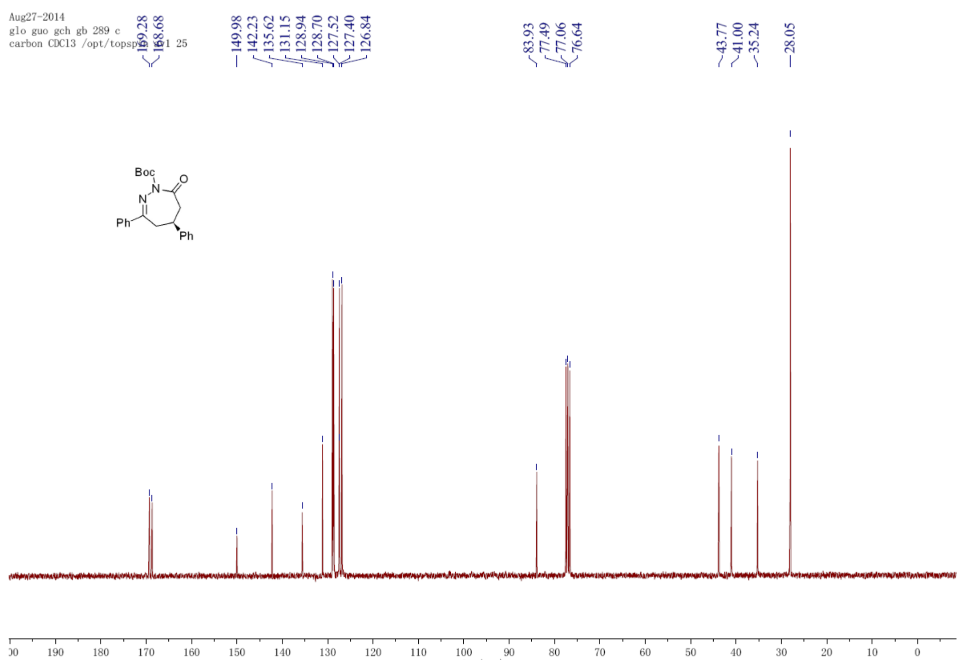




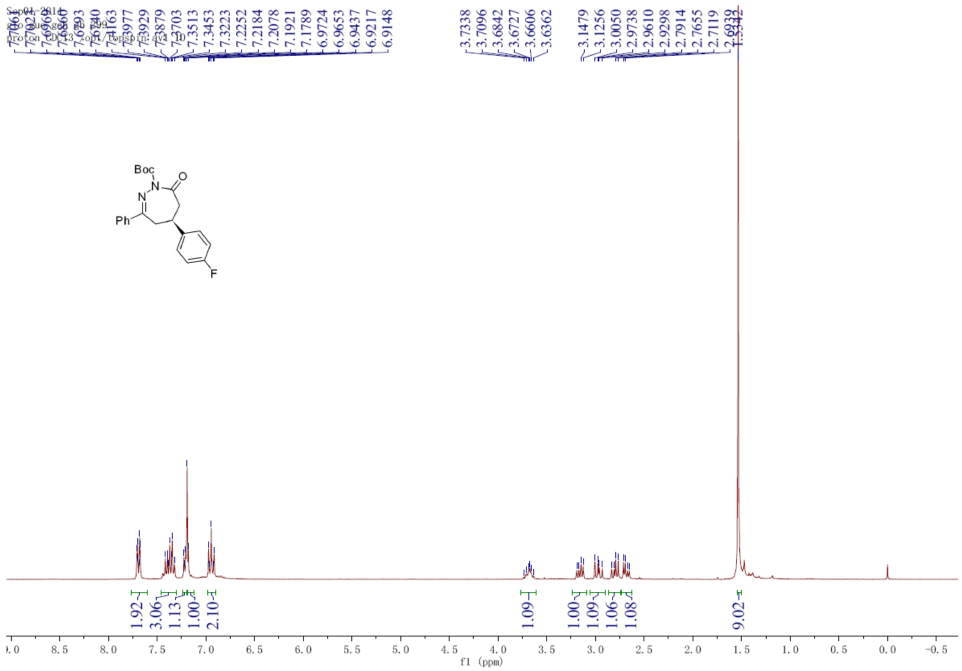
^{1}H NMR spectrum of **3ad**



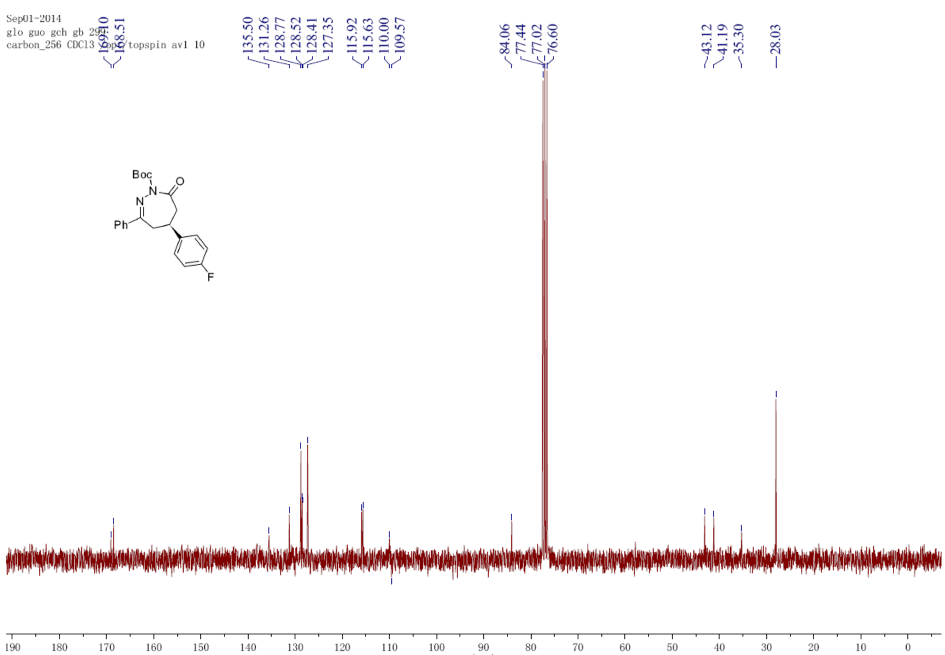
^{13}C NMR spectrum of **3ad**



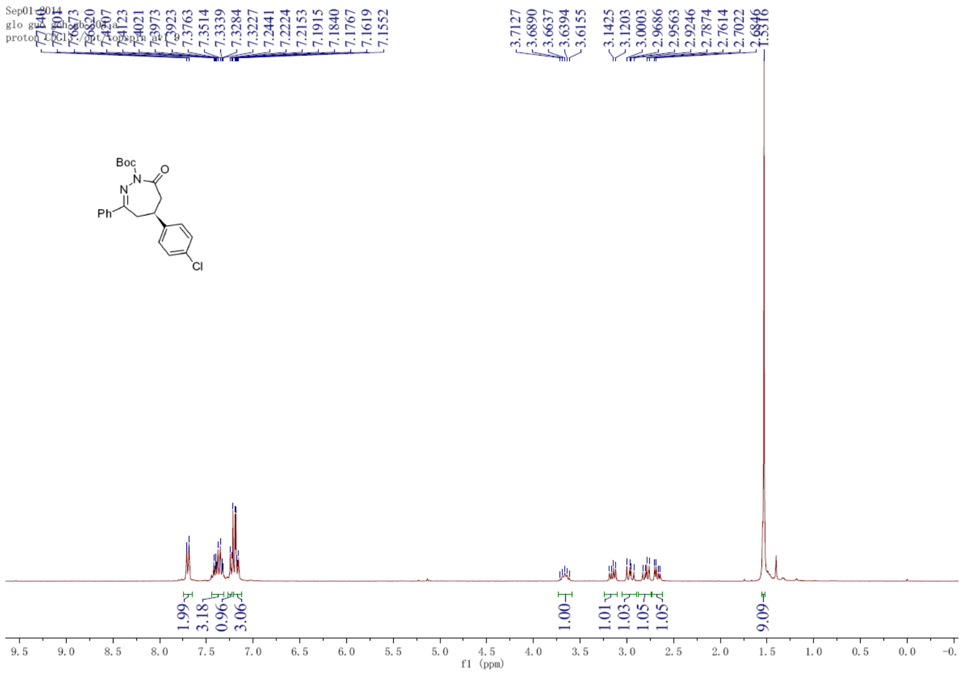
^{1}H NMR spectrum of **3bd**



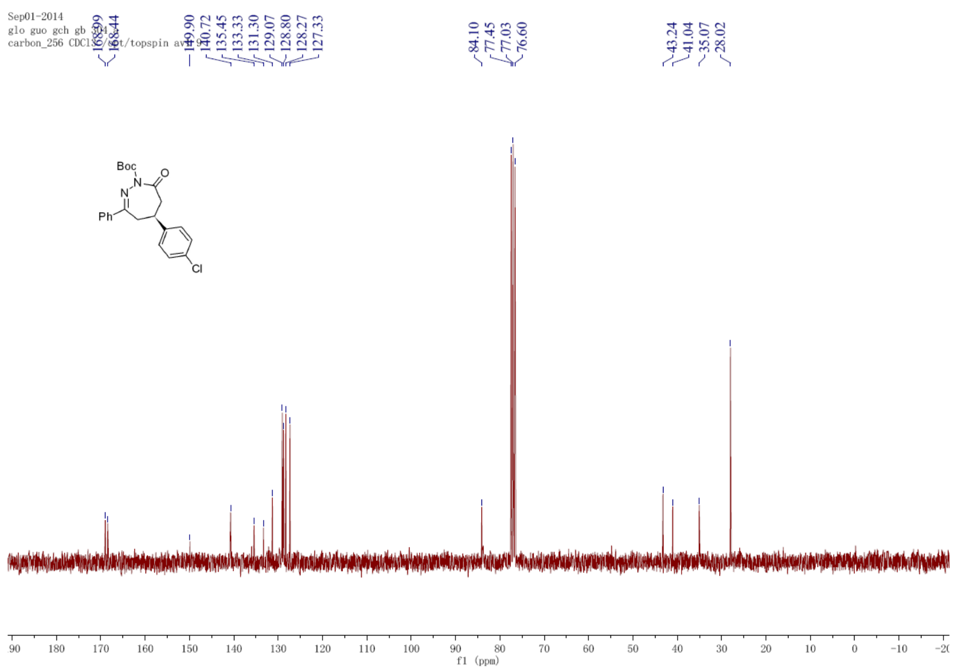
^{13}C NMR spectrum of **3bd**



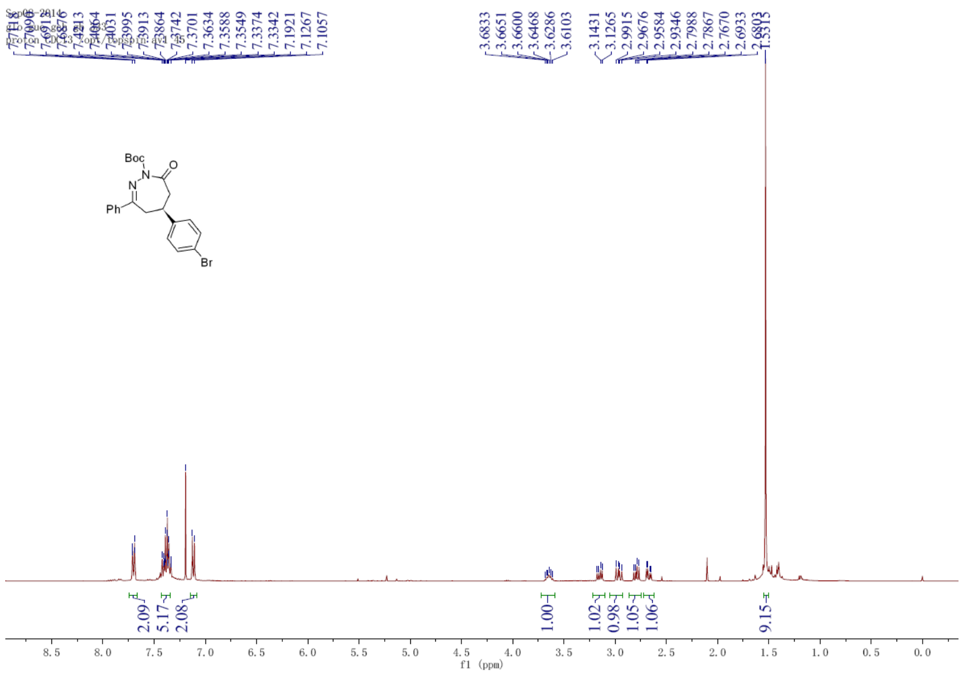
[1]H NMR spectrum of **3cd**



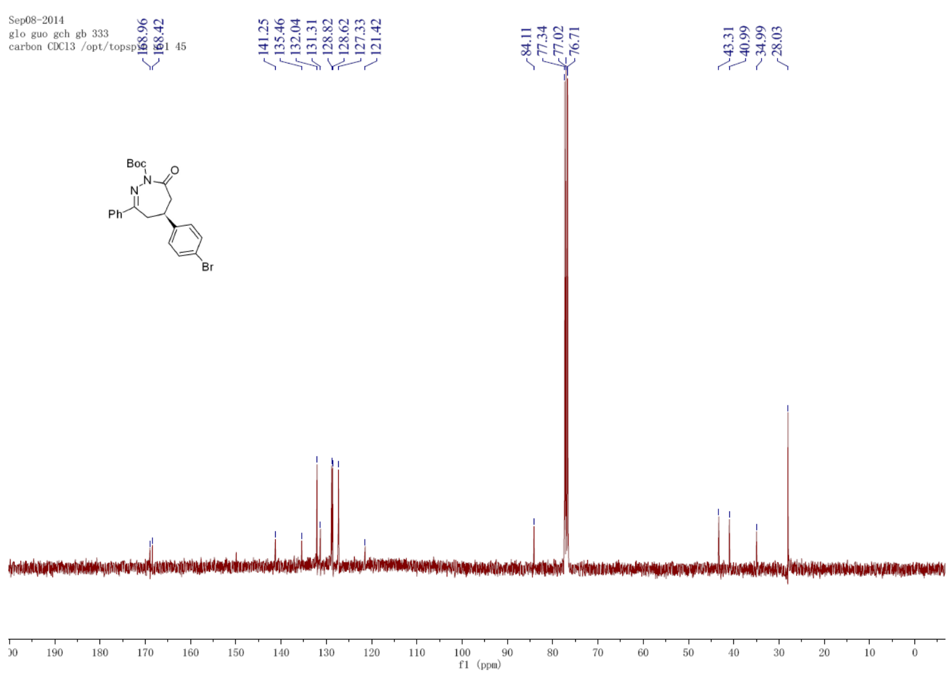
[13]C NMR spectrum of **3cd**



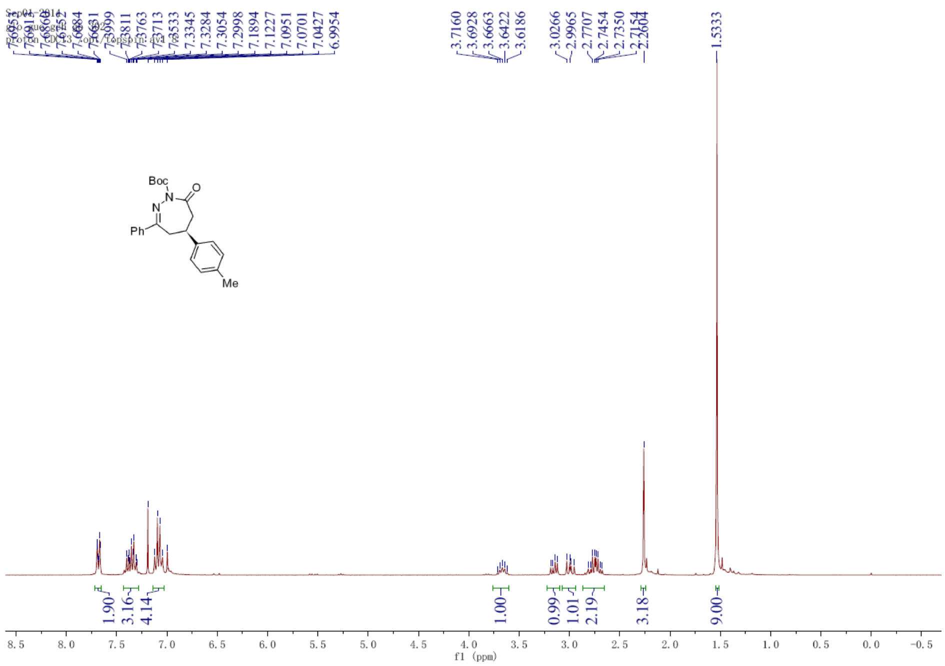
[1]H NMR spectrum of **3dd**



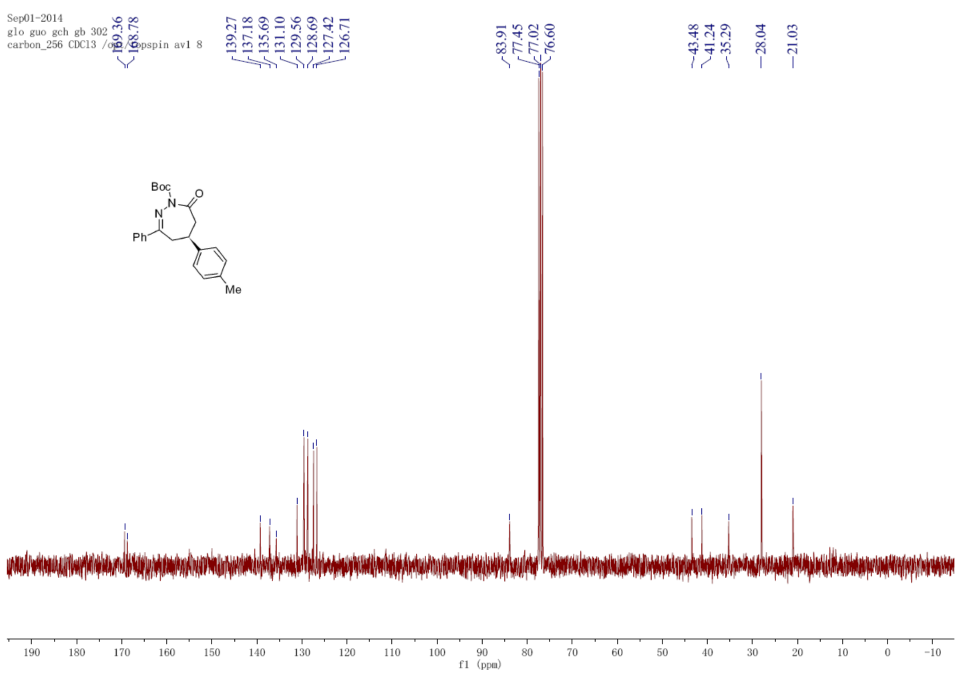
[13]C NMR spectrum of **3dd**



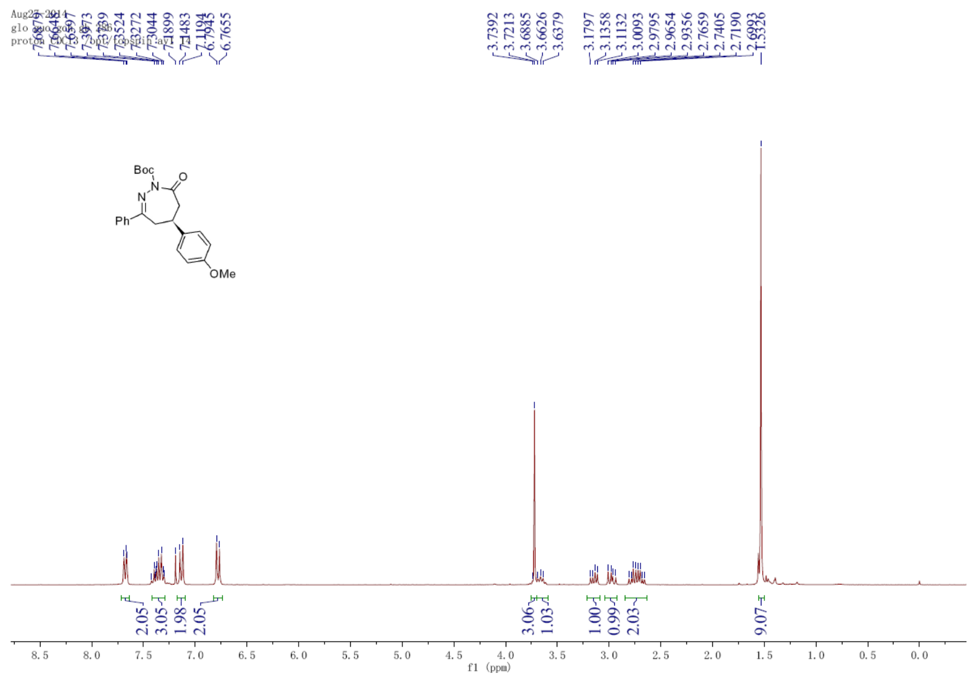
[1]H NMR spectrum of **3ed**



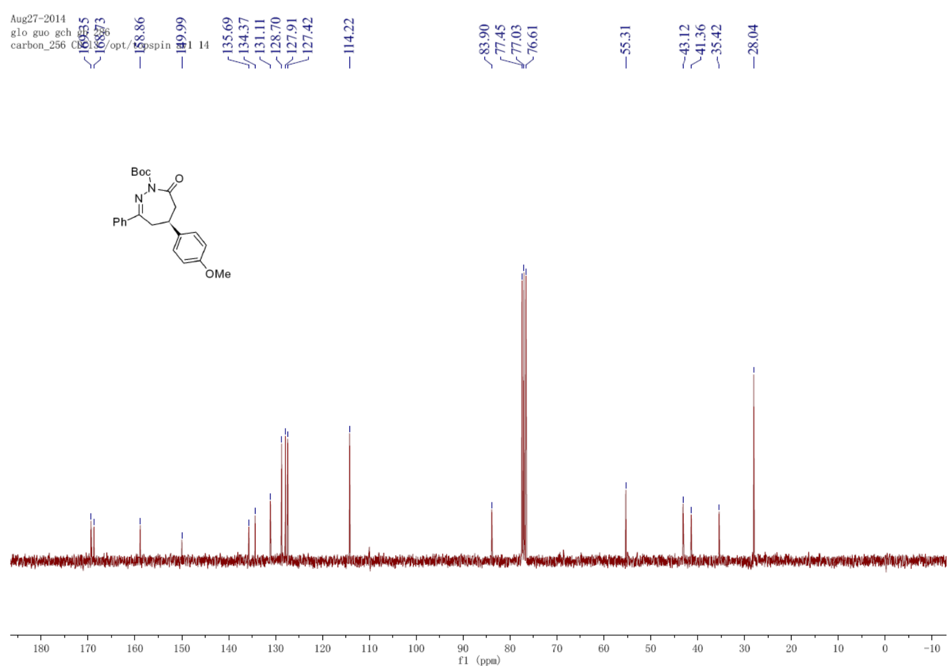
[13]C NMR spectrum of **3ed**



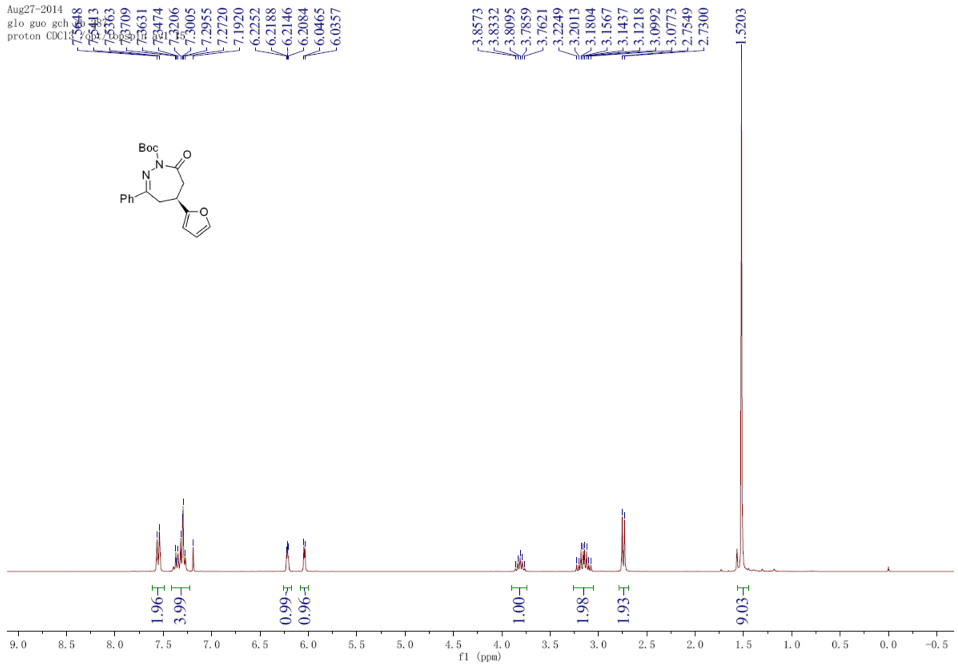
^{1}H NMR spectrum of **3fd**



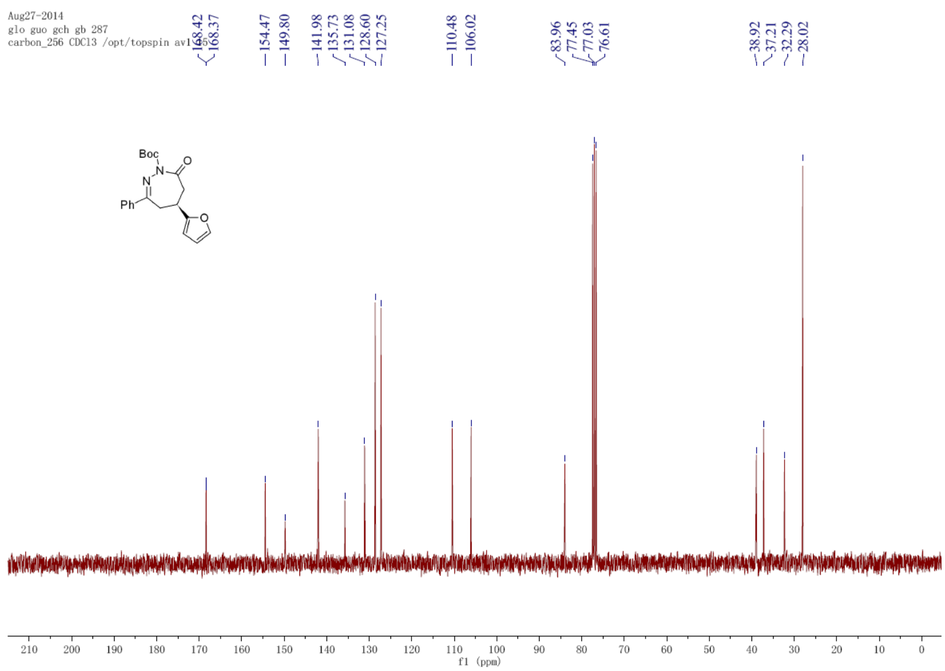
^{13}C NMR spectrum of **3fd**



^{1}H NMR spectrum of **3gd**



^{13}C NMR spectrum of **3gd**



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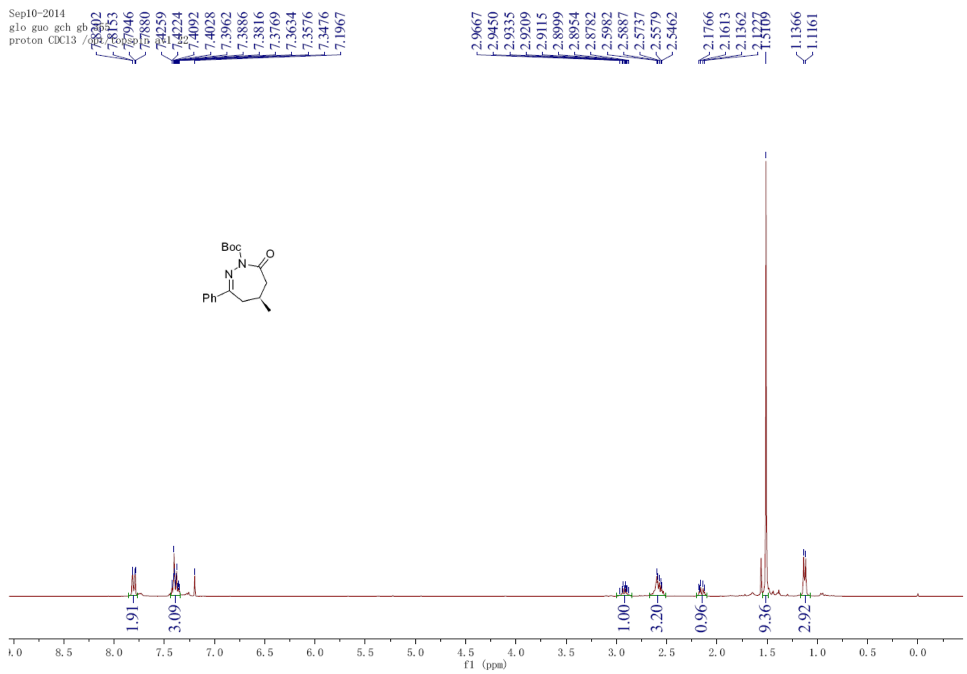
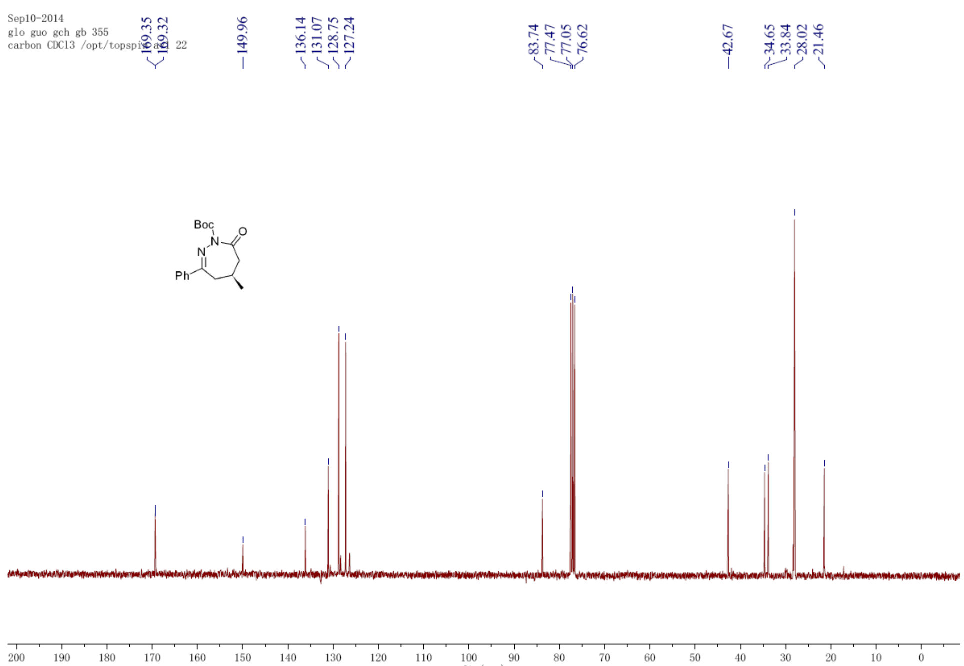


[13]C NMR spectrum of **3hd**



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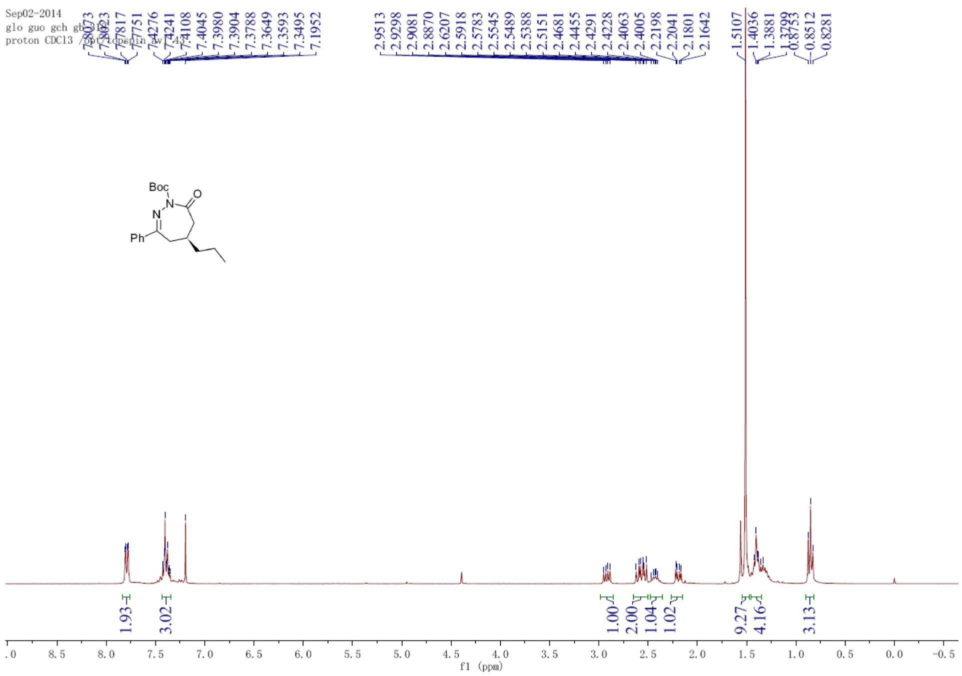
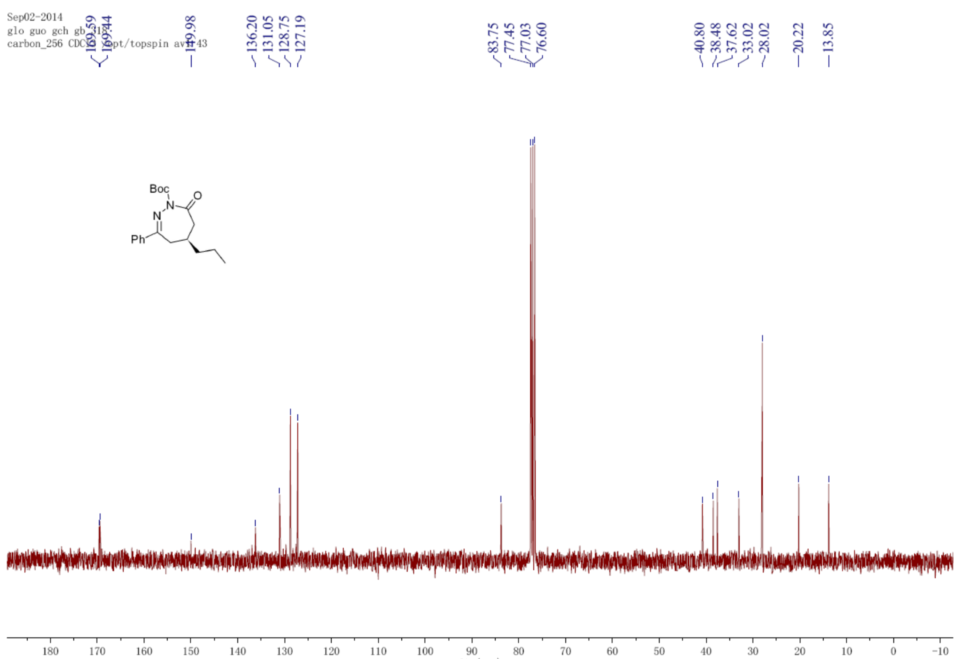
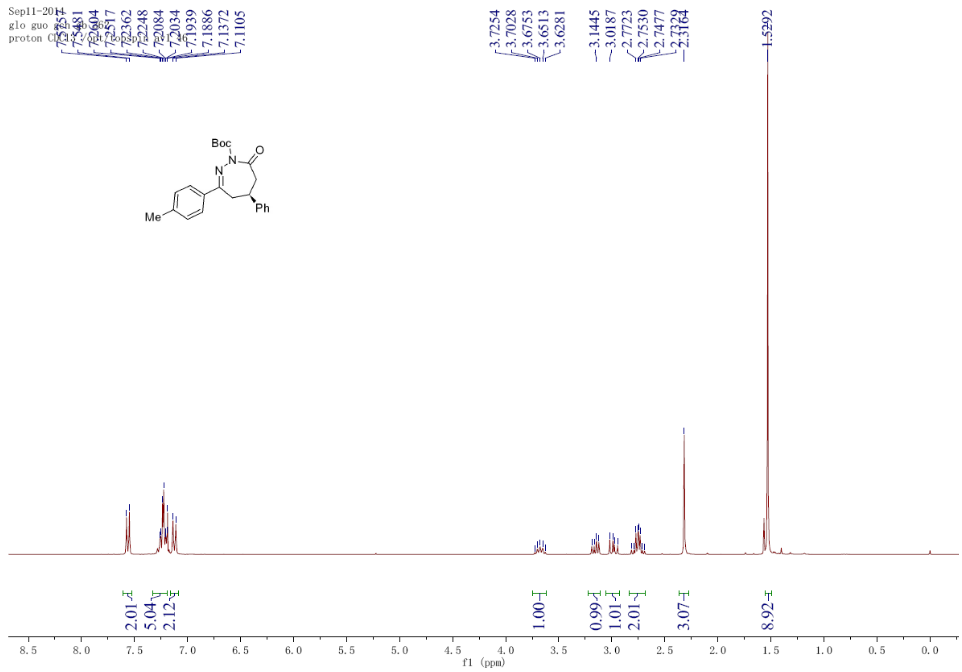


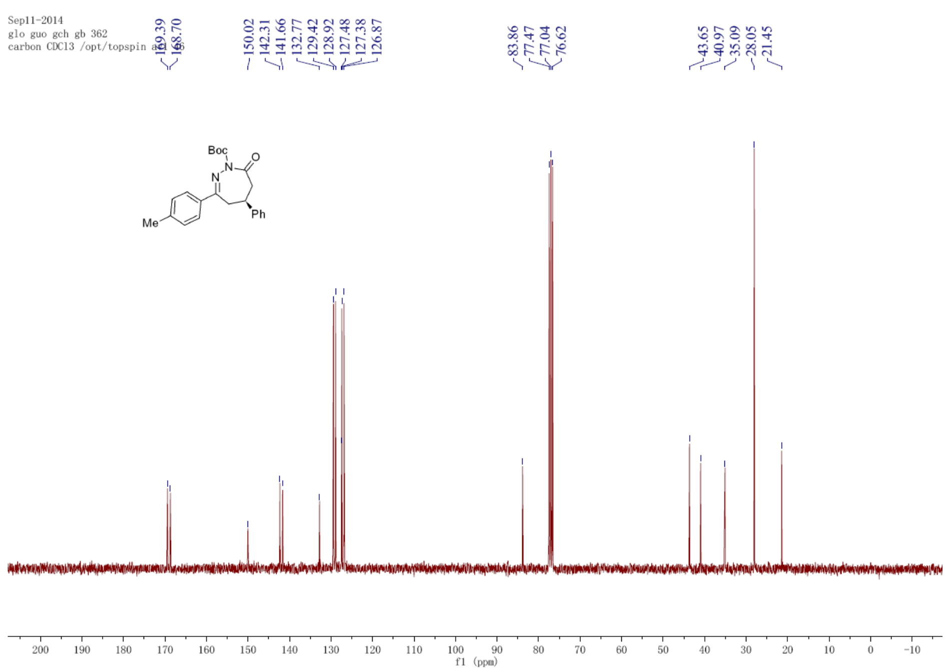
^{13}C NMR spectrum of **3id**



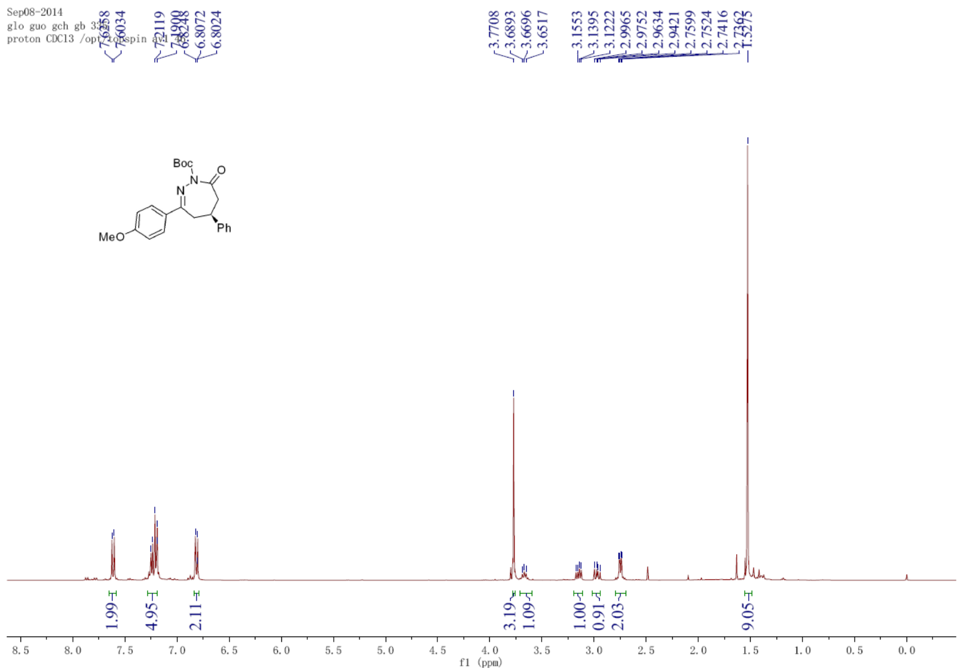
[1]H NMR spectrum of **3ae**



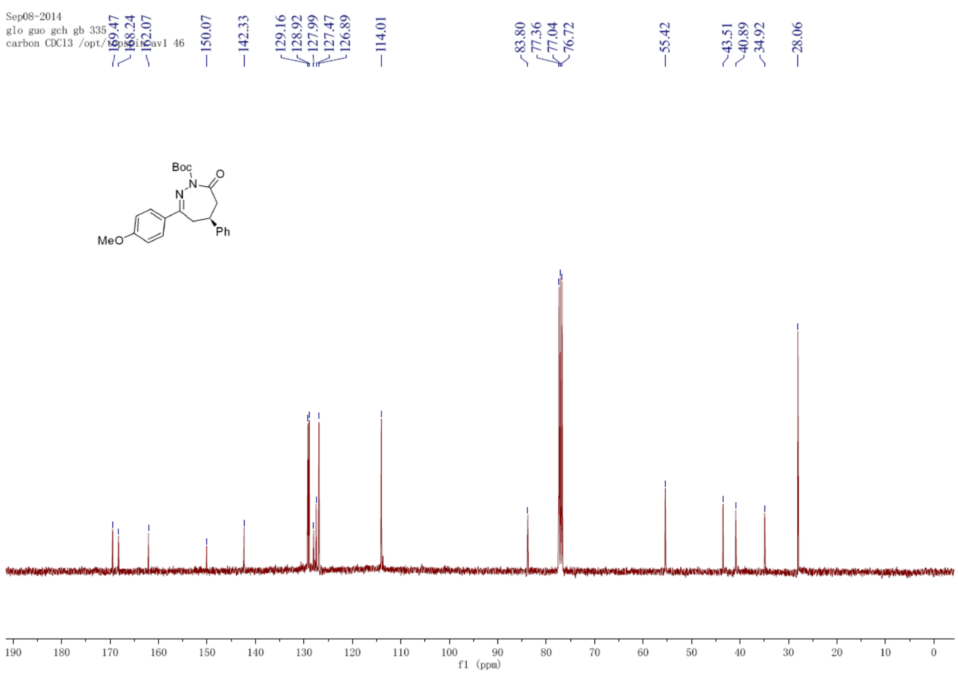
[13]C NMR spectrum of **3ae**



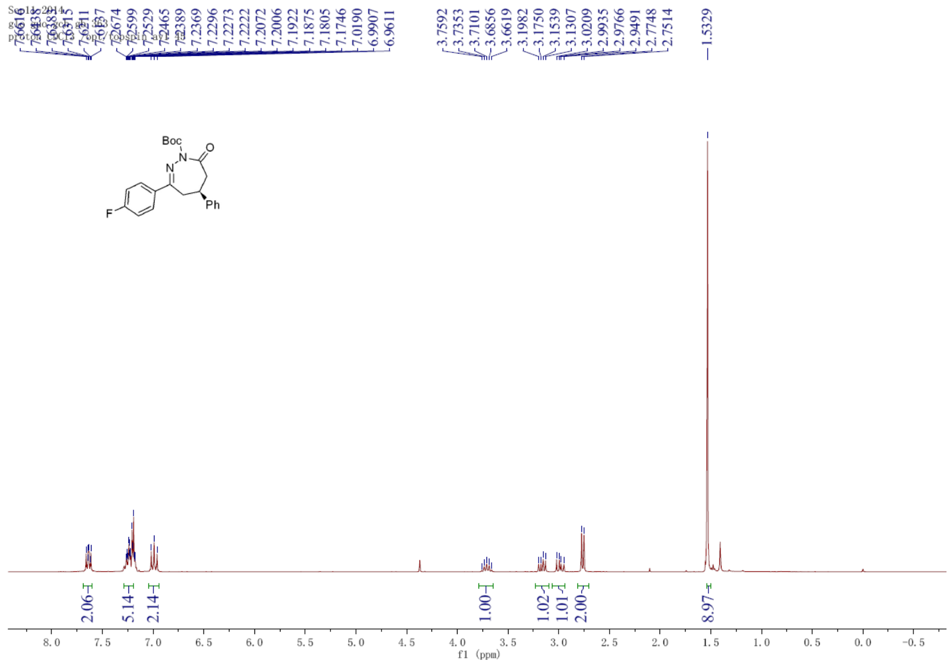
^{1}H NMR spectrum of **3af**



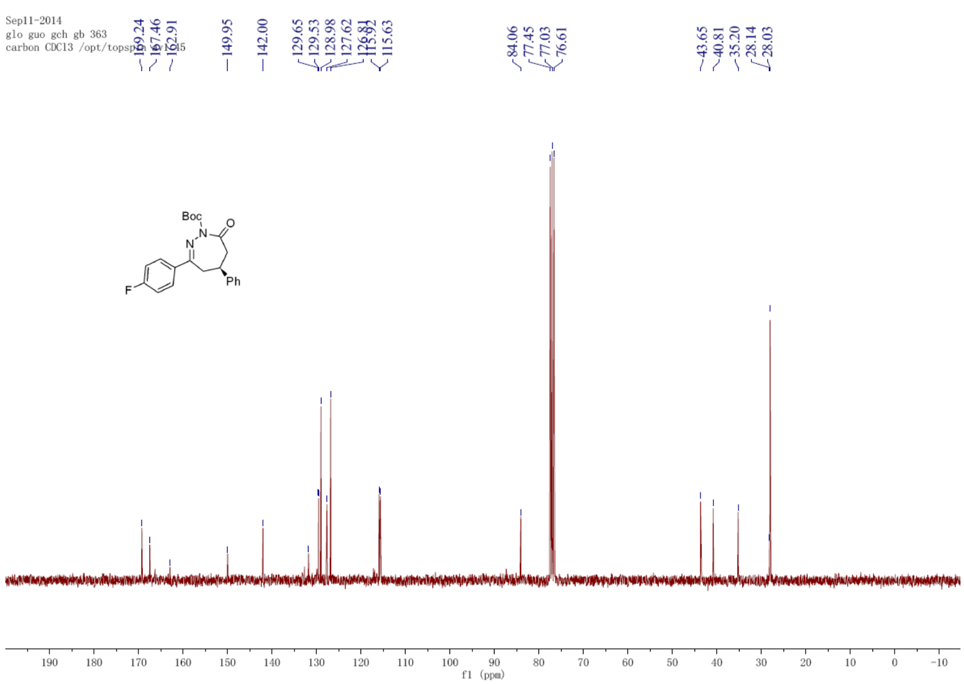
^{13}C NMR spectrum of **3af**



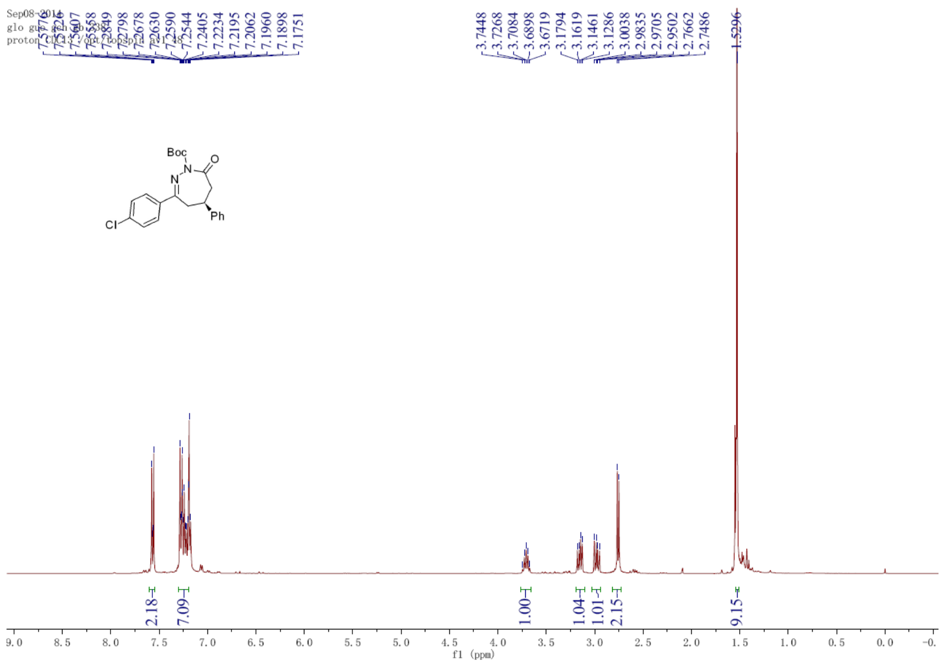
^{1}H NMR spectrum of **3ag**



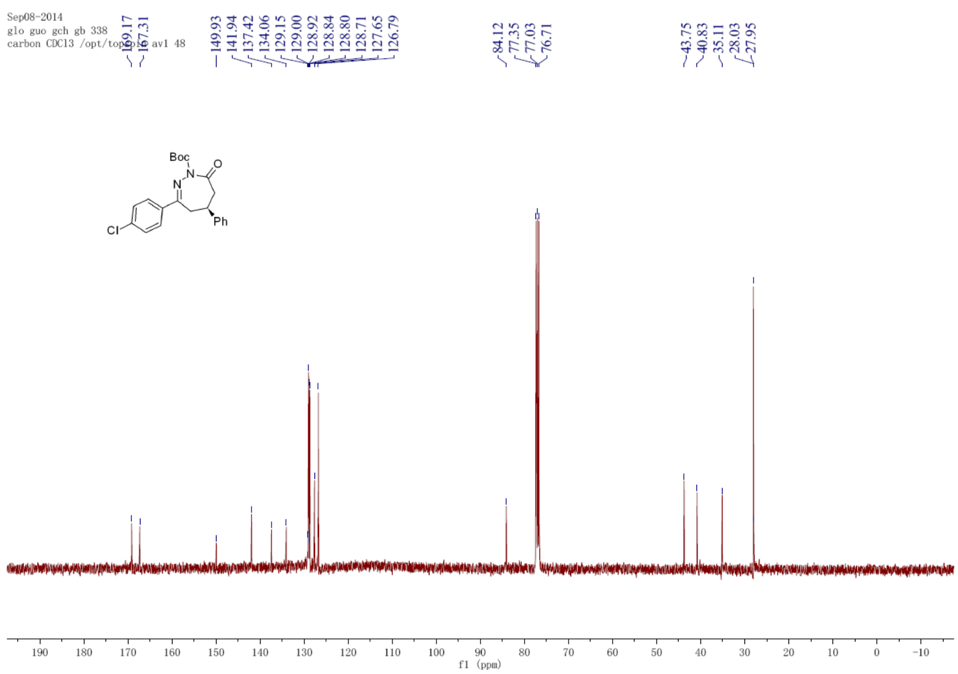
^{13}C NMR spectrum of **3ag**



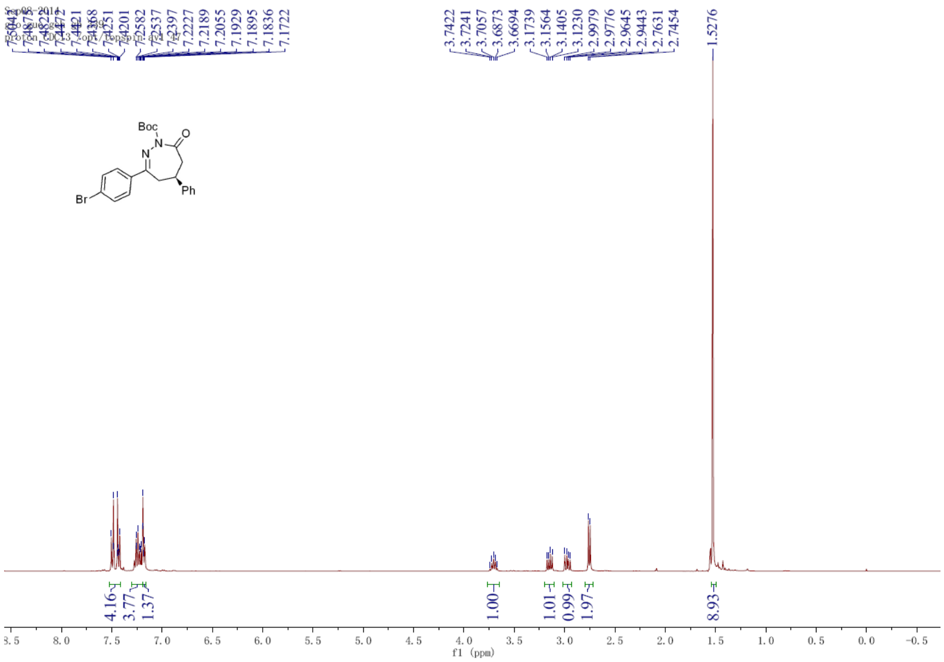
^{1}H NMR spectrum of **3ah**



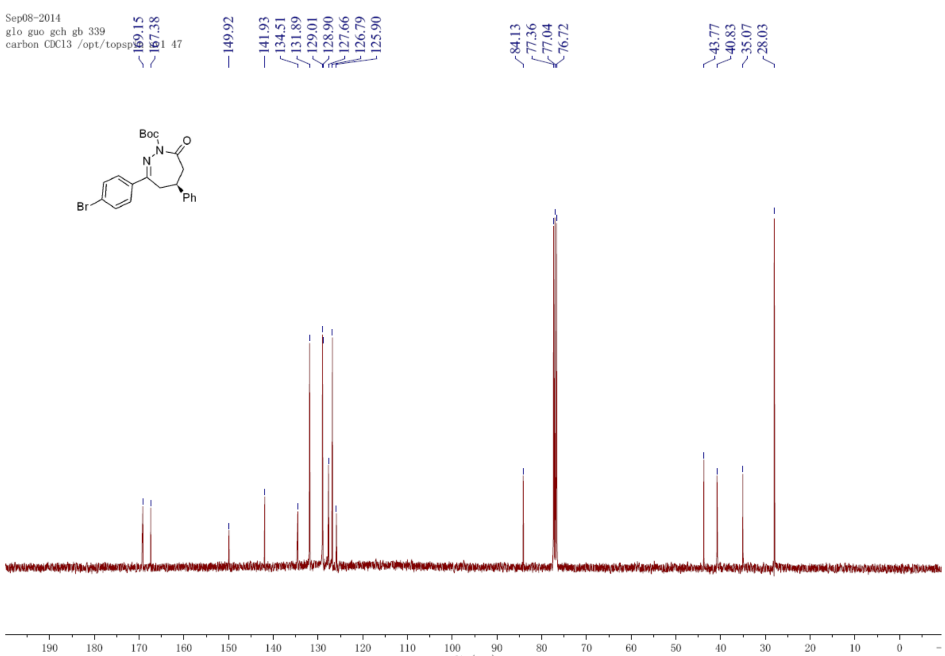
^{13}C NMR spectrum of **3ah**



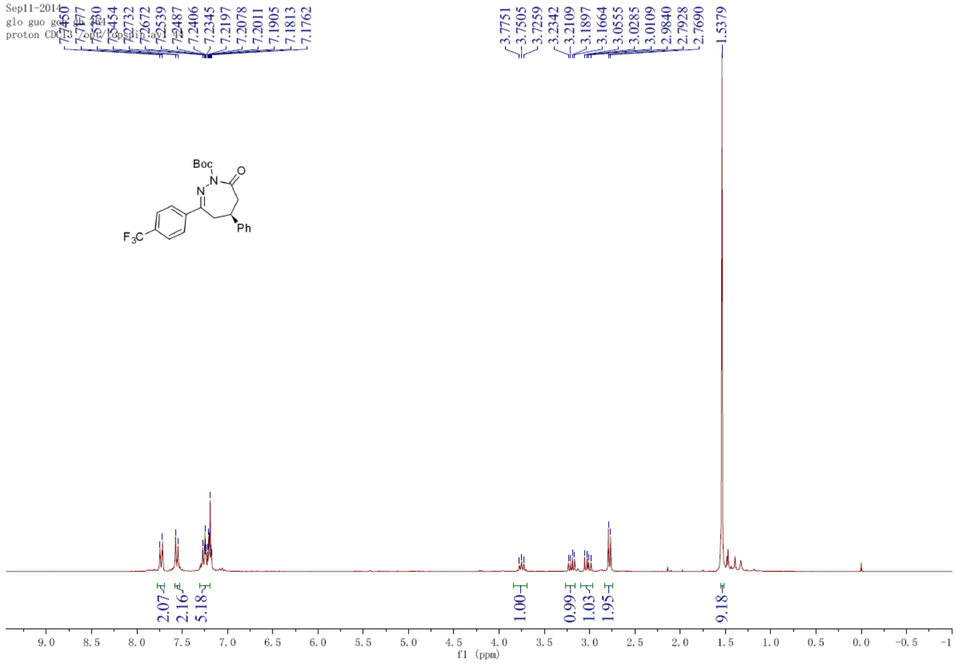
^{1}H NMR spectrum of **3ai**



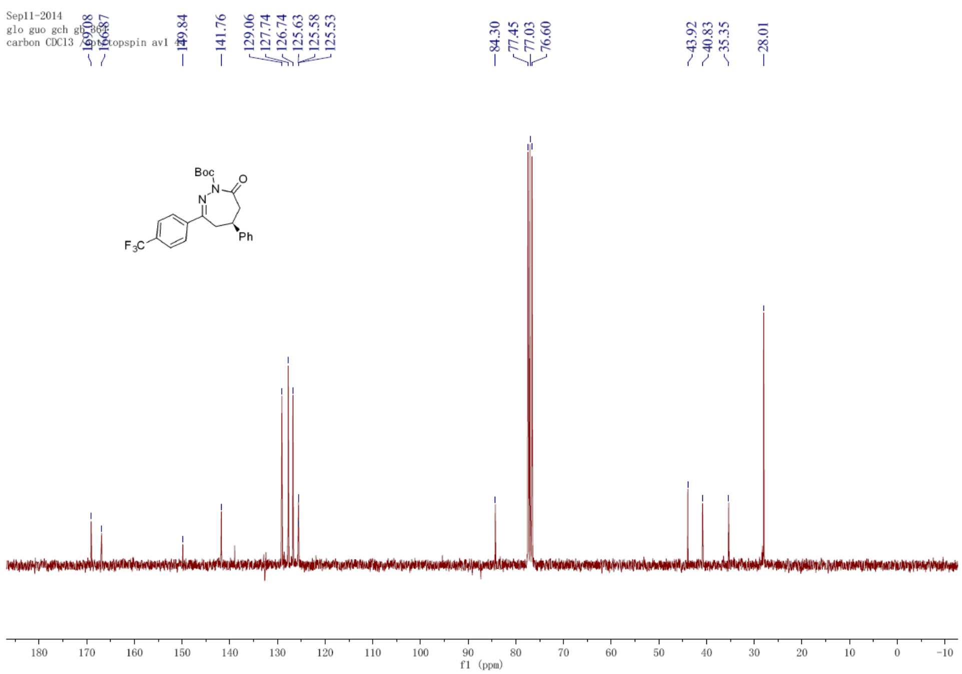
^{13}C NMR spectrum of **3ai**



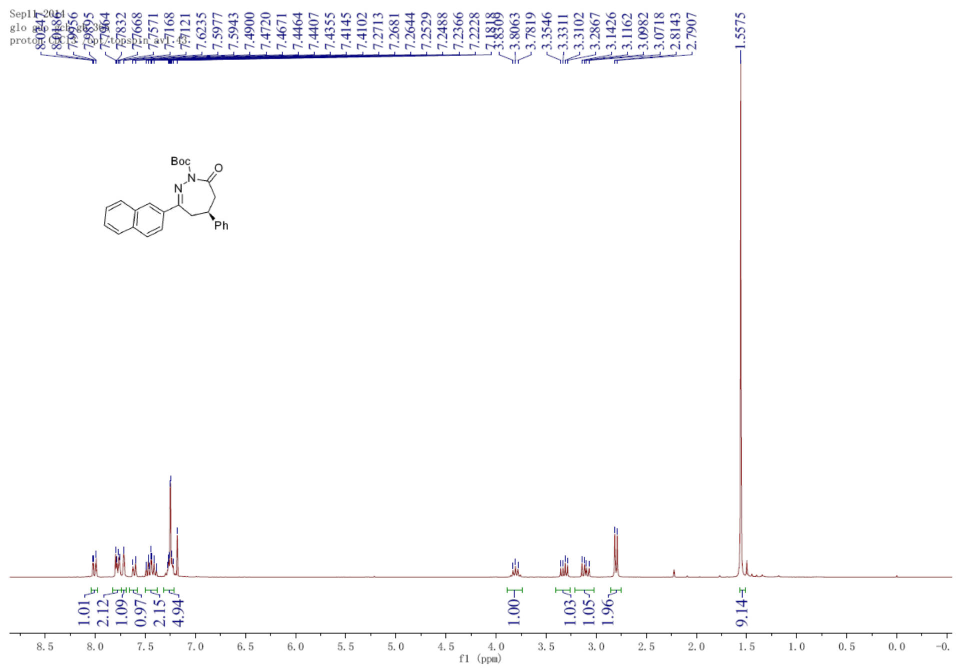
^{1}H NMR spectrum of **3aj**



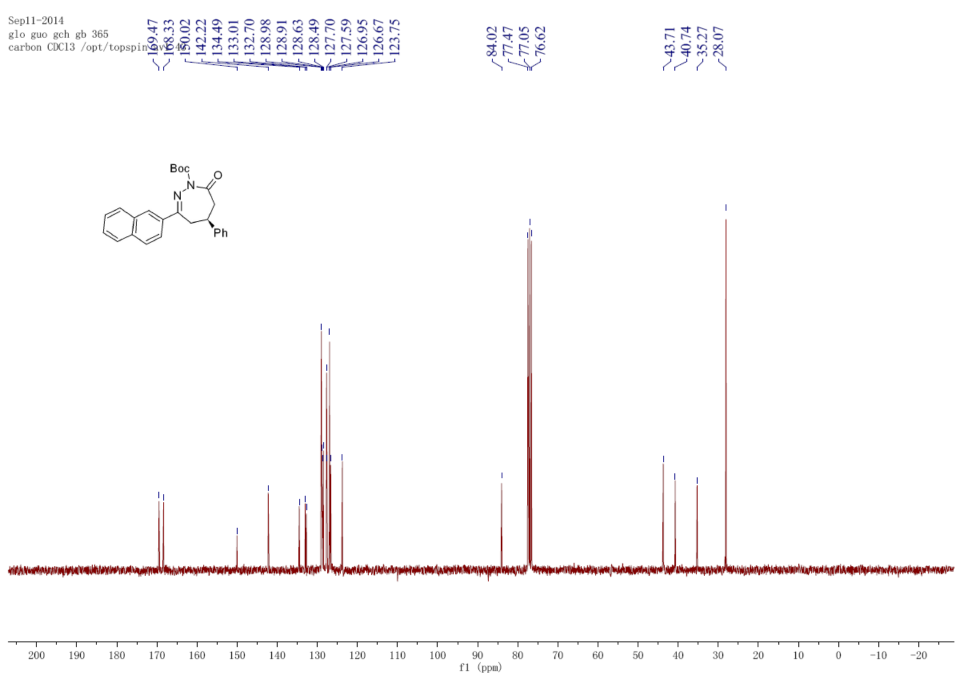
^{13}C NMR spectrum of **3aj**



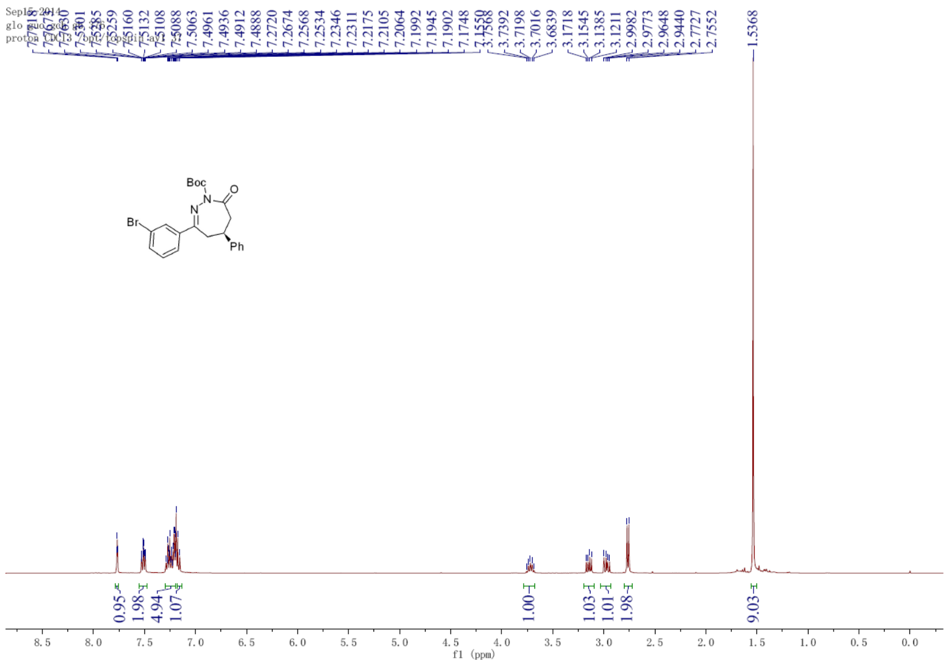
^{1}H NMR spectrum of **3ak**



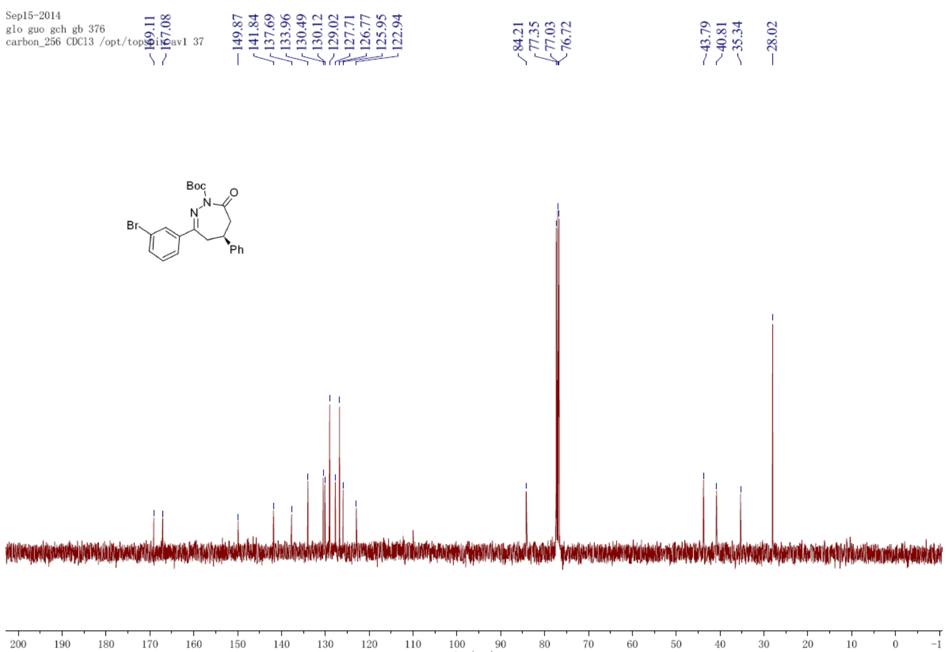
^{13}C NMR spectrum of **3ak**



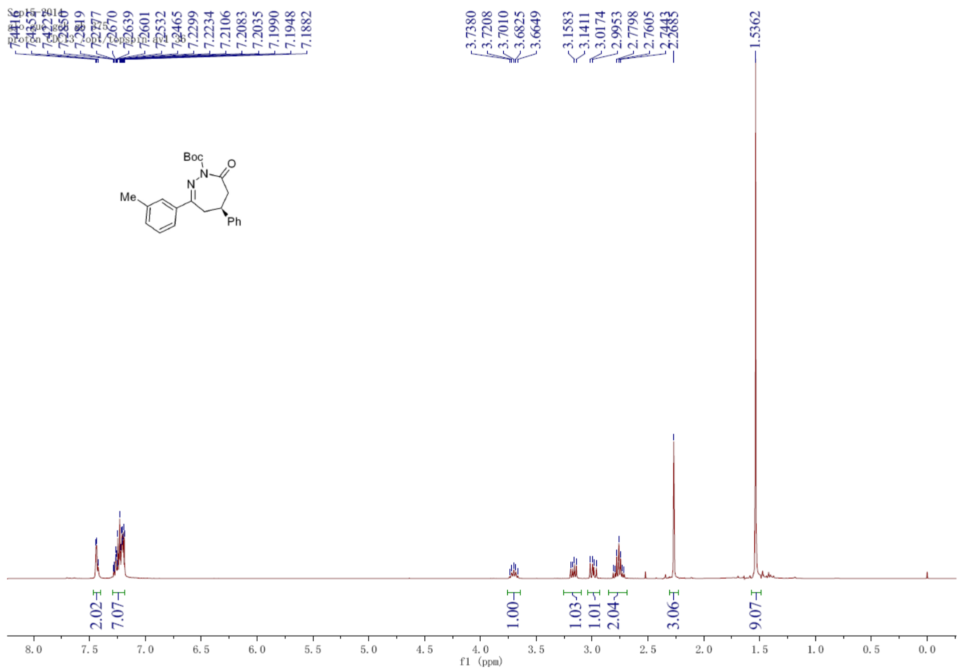
^{1}H NMR spectrum of **3al**



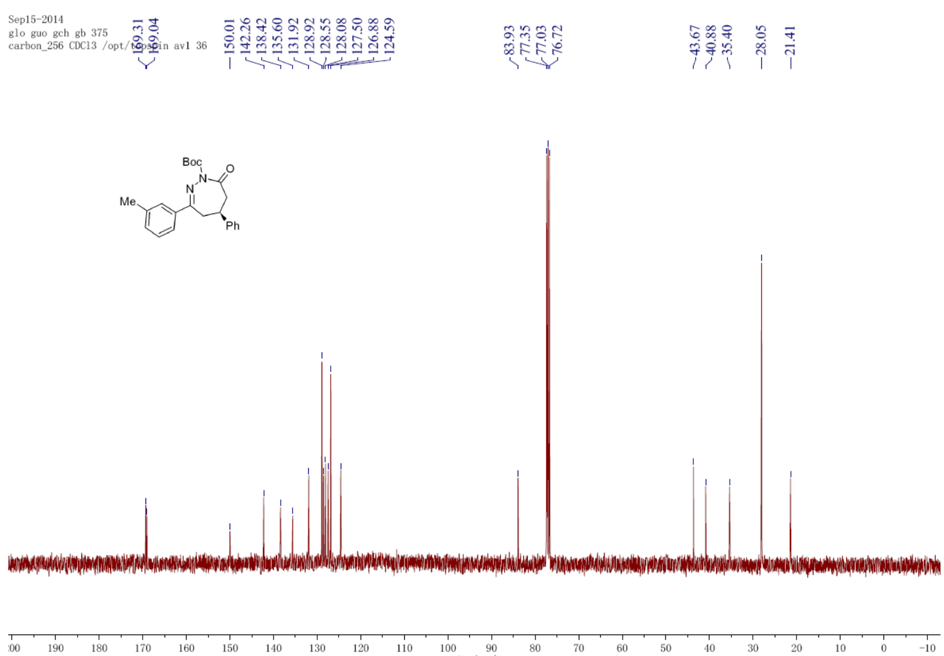
^{13}C NMR spectrum of **3al**



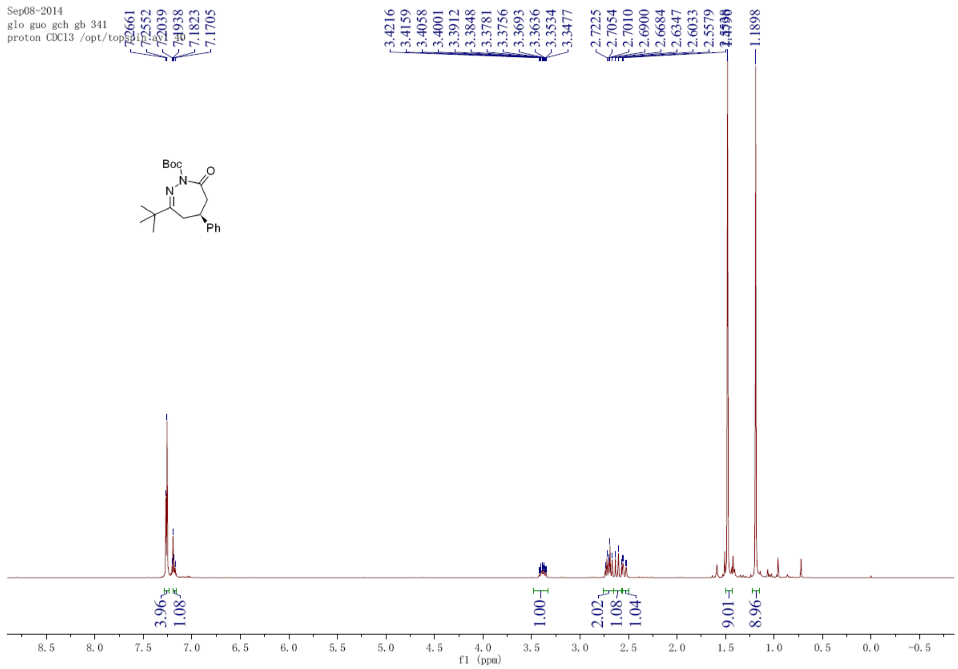
[1]H NMR spectrum of **3am**



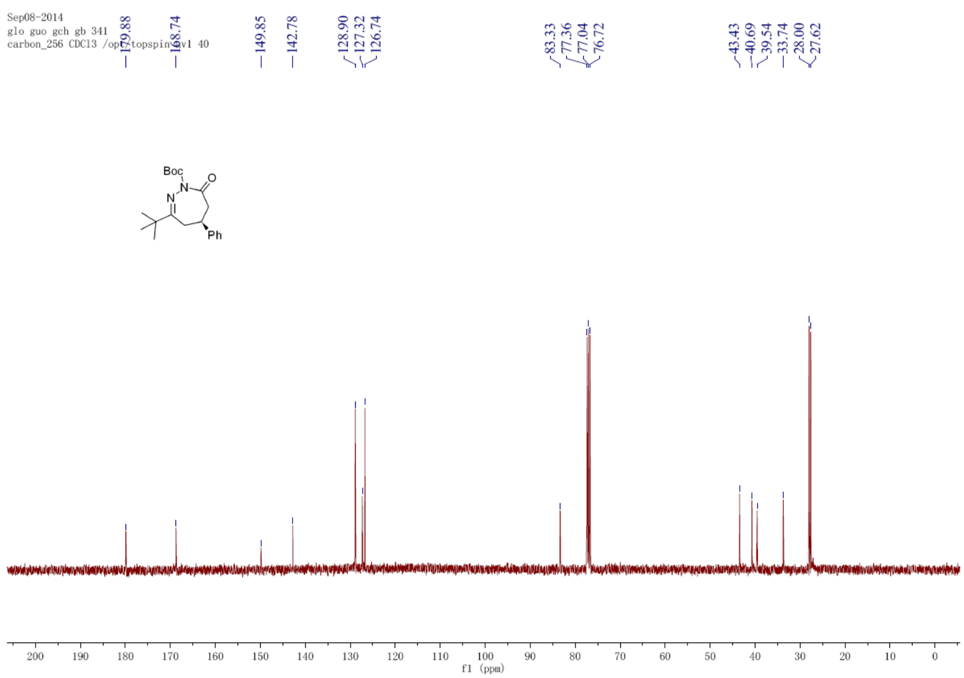
[13]C NMR spectrum of **3am**



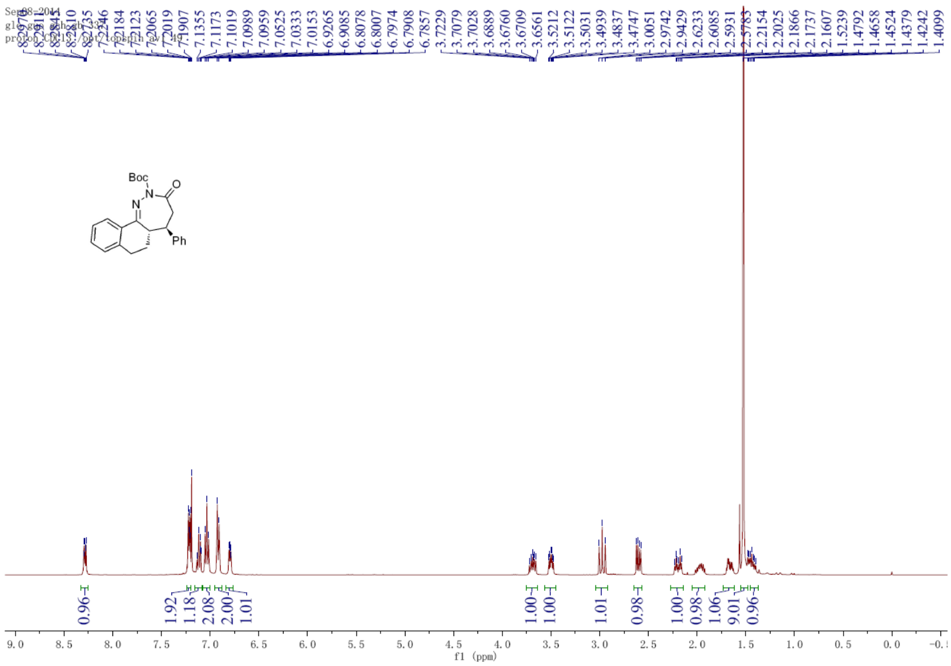
[1]H NMR spectrum of **3an**



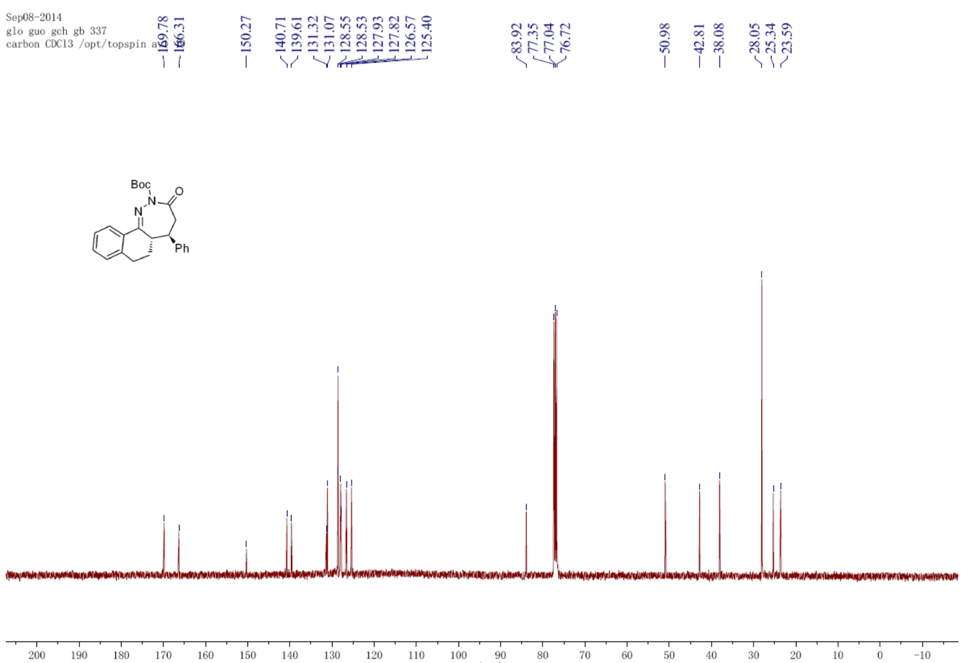
[13]C NMR spectrum of **3an**



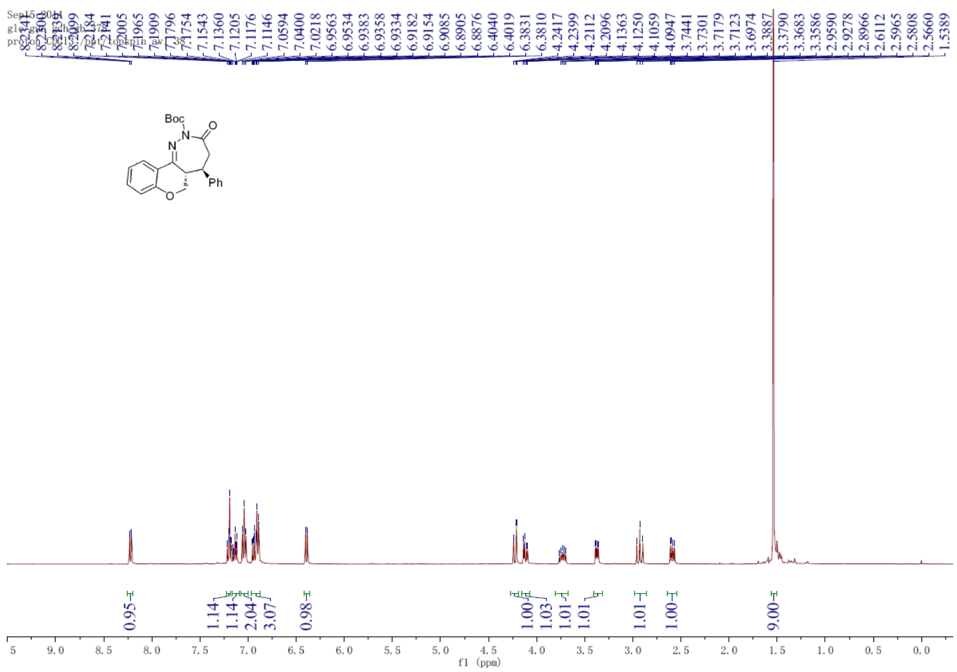
[1]H NMR spectrum of **3ao**



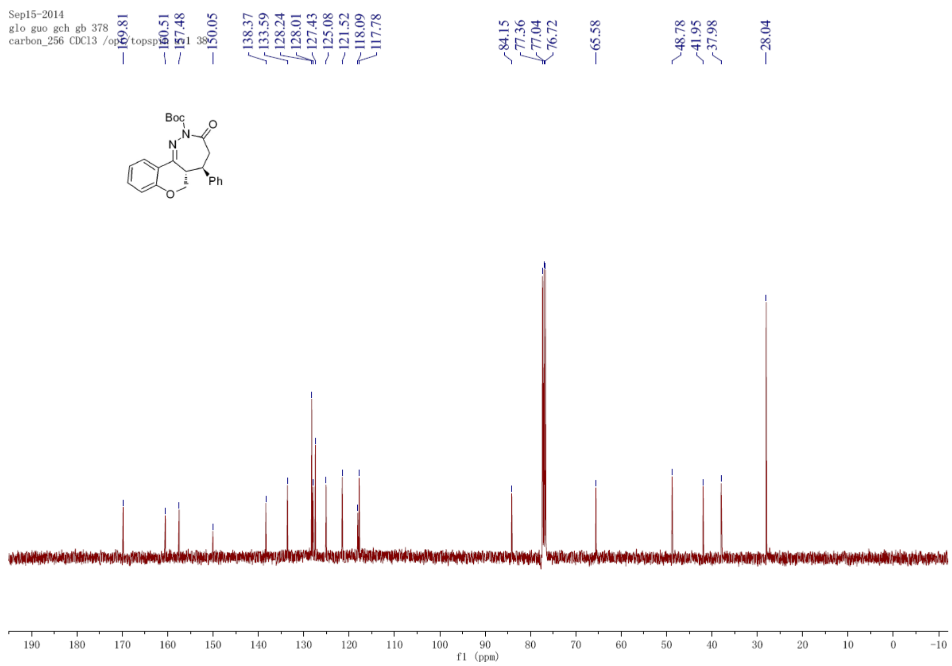
[13]C NMR spectrum of **3ao**



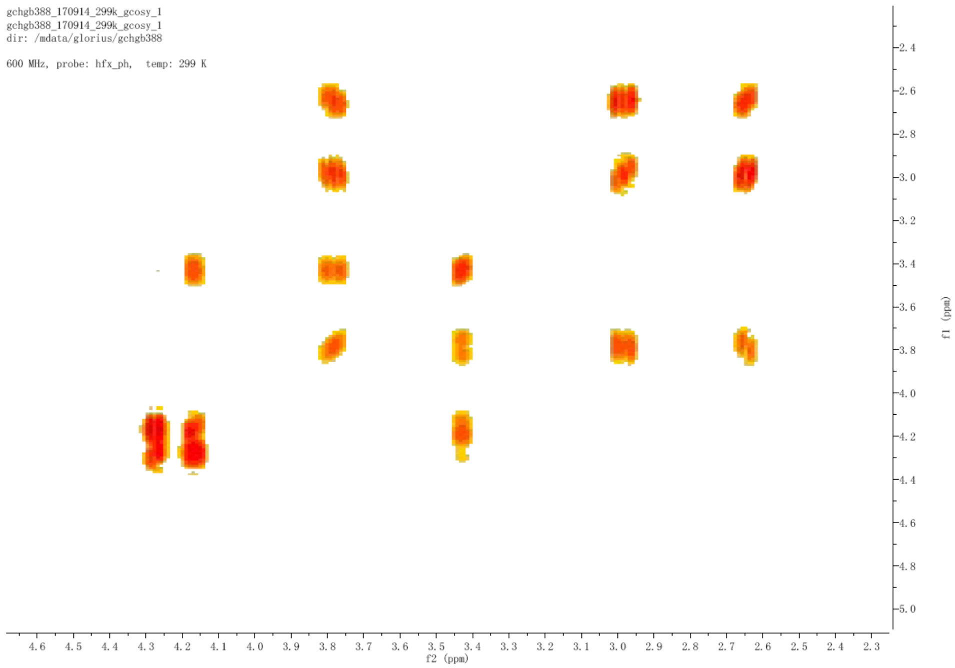
^{1}H NMR spectrum of **3ap**



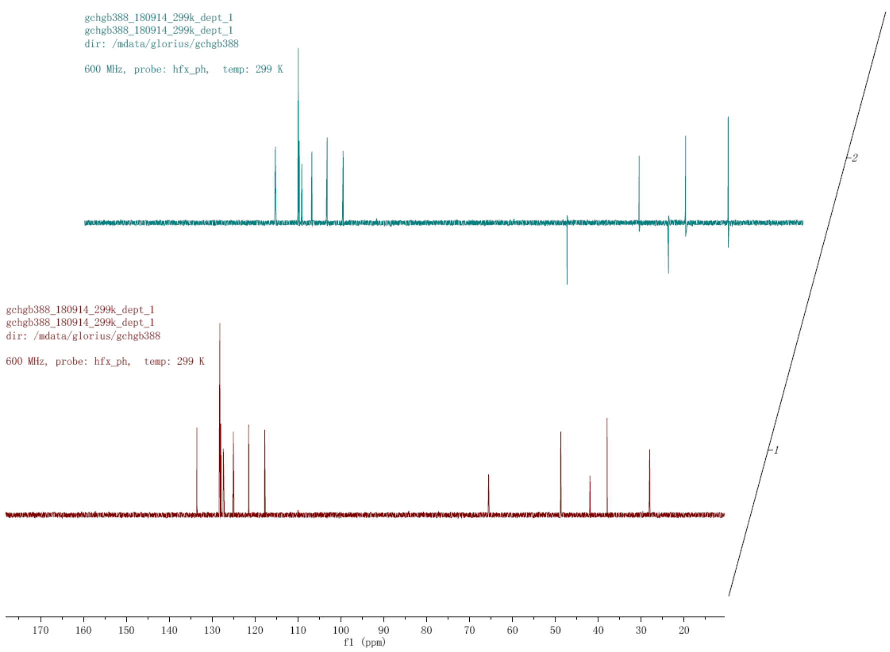
^{13}C NMR spectrum of **3ap**



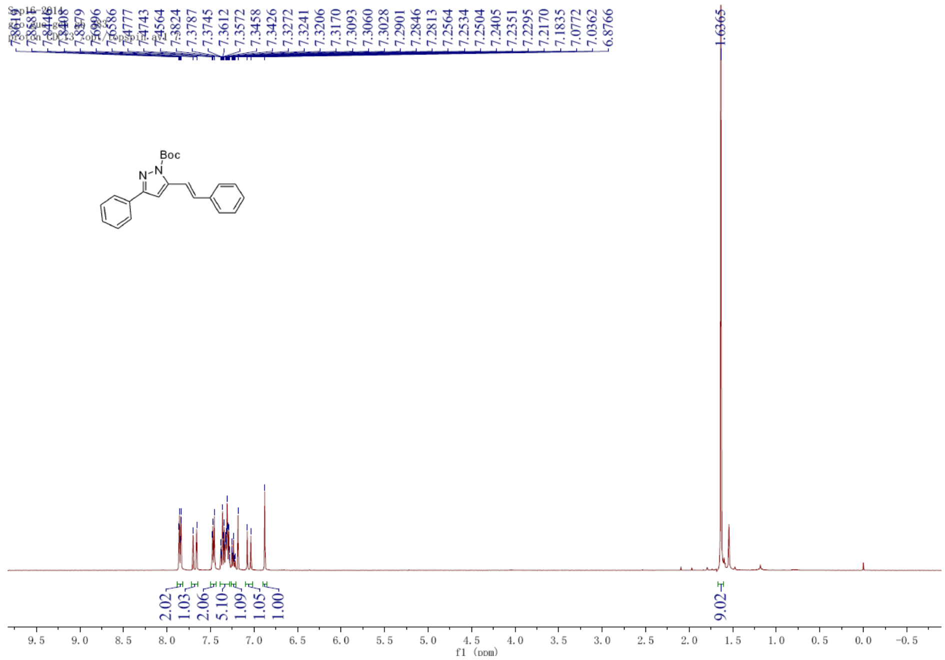
gcosy spectrum of **3ap**



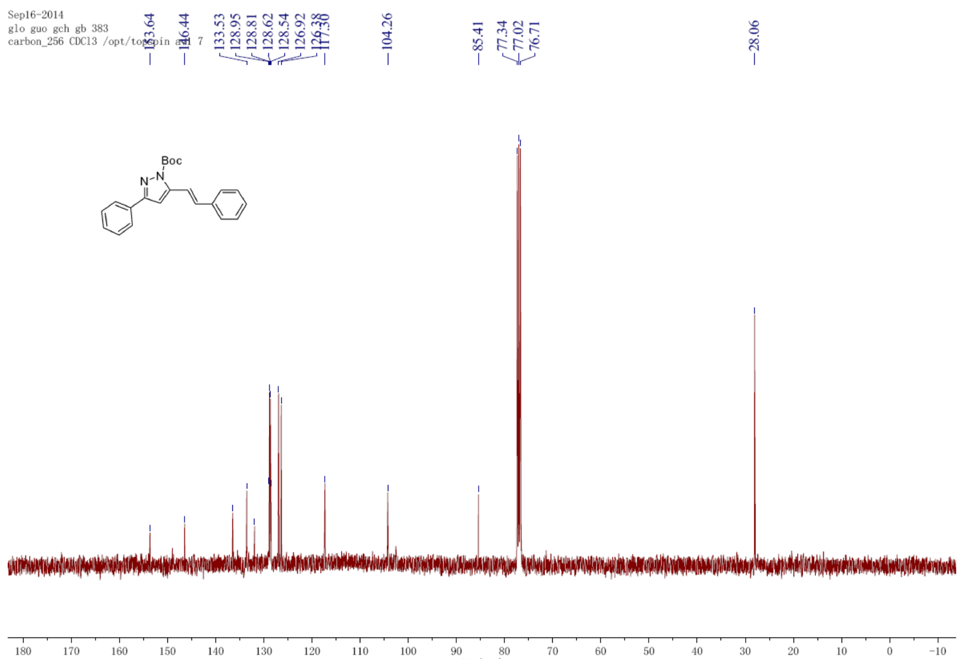
dept spectrum of **3ap**



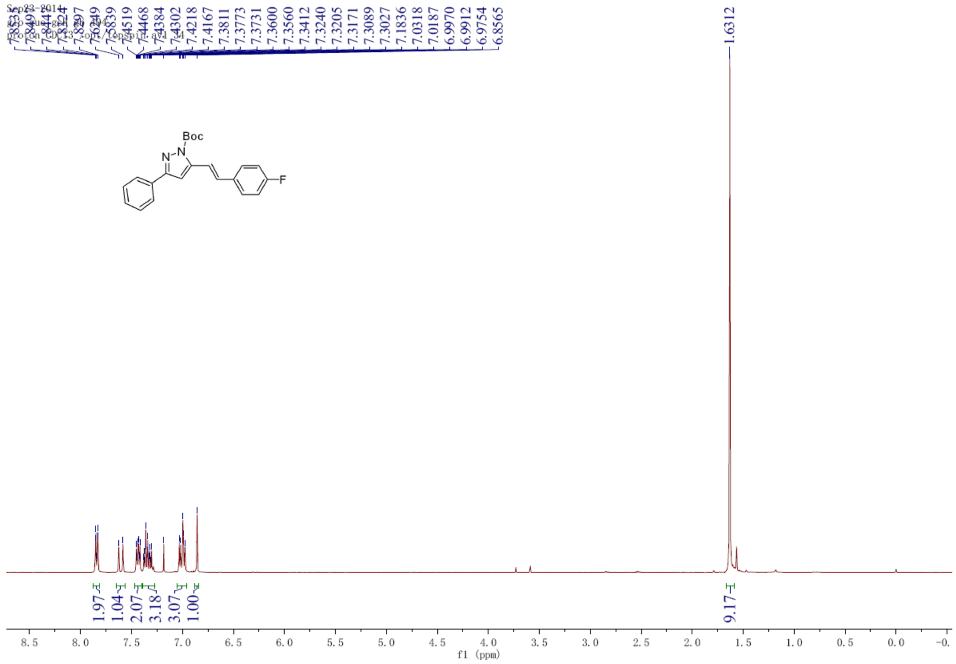
[1]H NMR spectrum of **4ad**



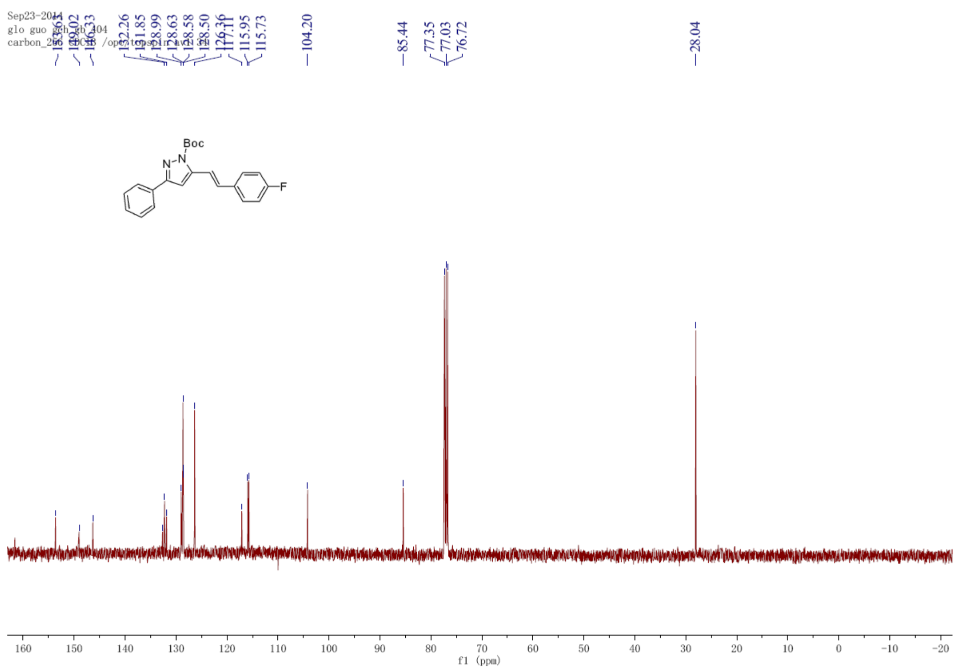
[13]C NMR spectrum of **4ad**



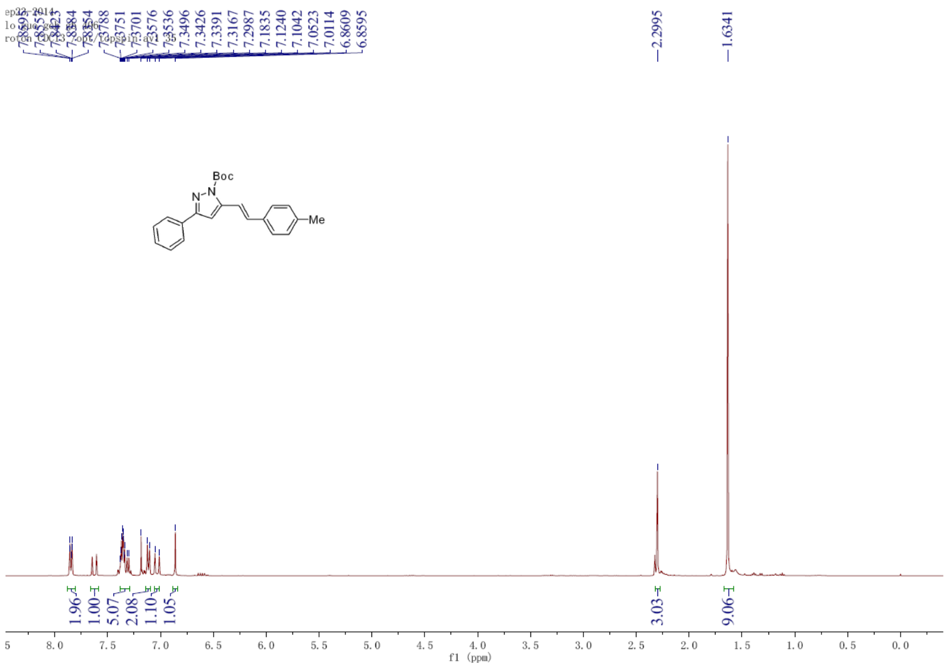
[1]H NMR spectrum of **4bd**



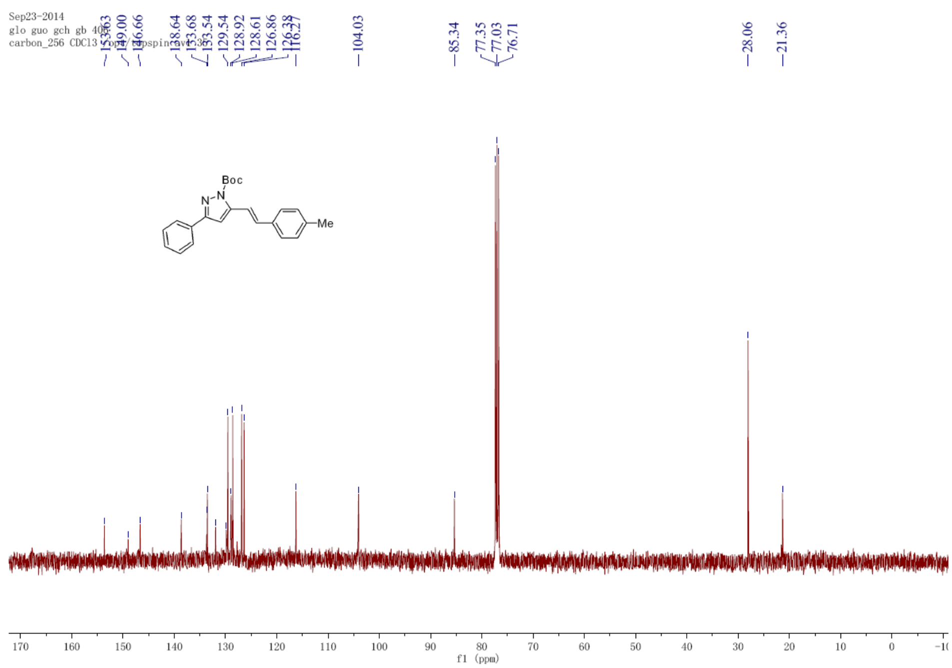
[13]C NMR spectrum of **4bd**



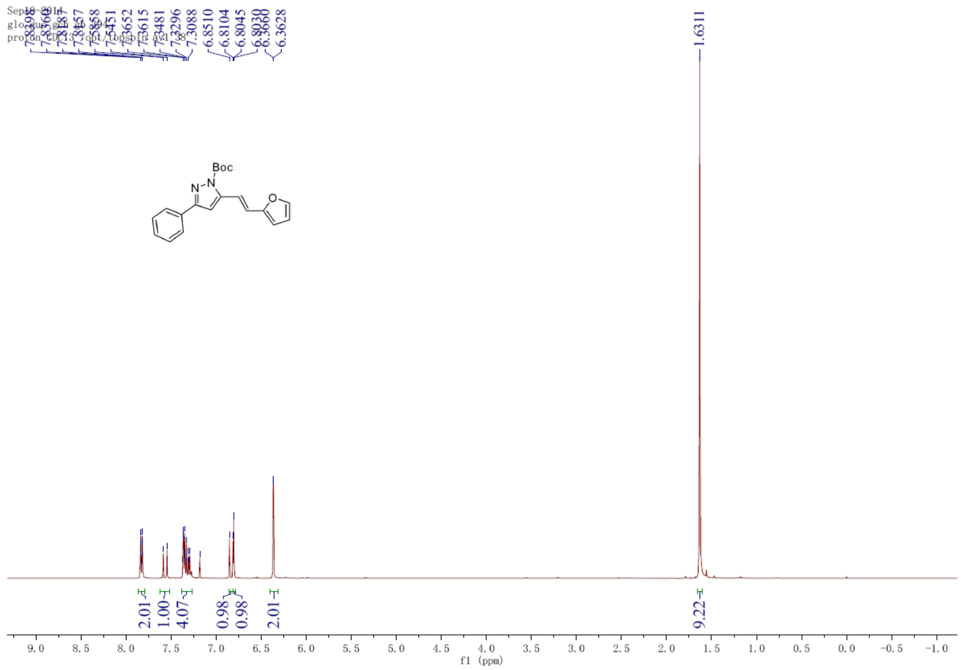
^{1}H NMR spectrum of **4ed**



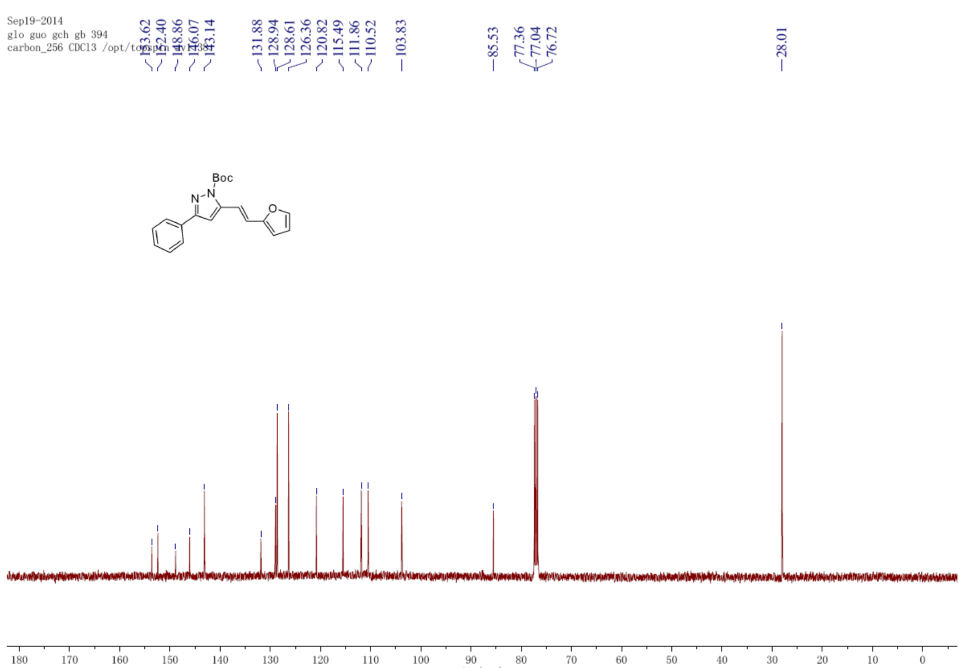
^{13}C NMR spectrum of **4ed**



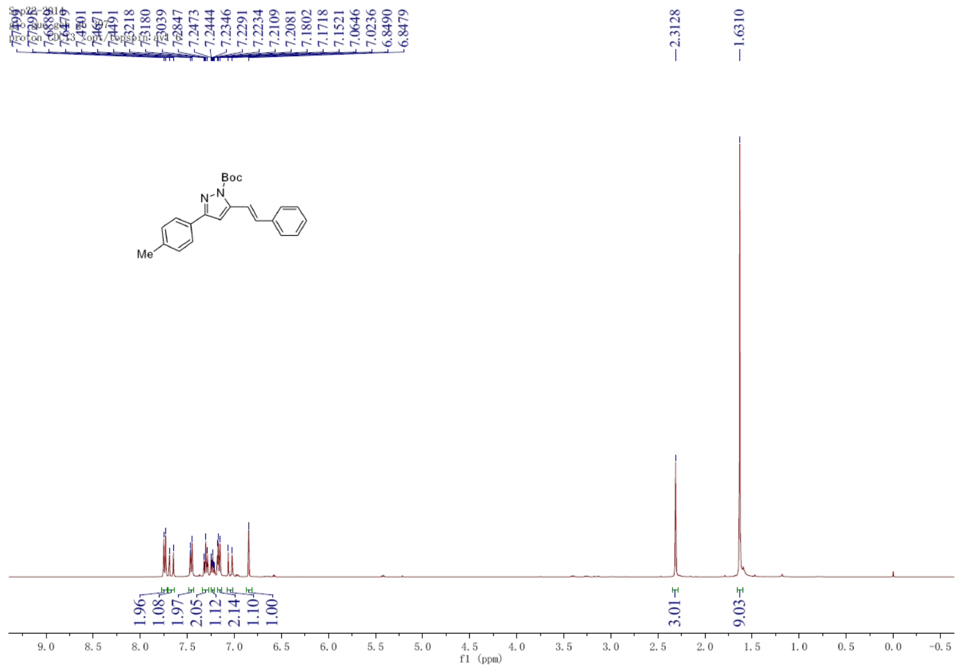
[1]H NMR spectrum of **4gd**



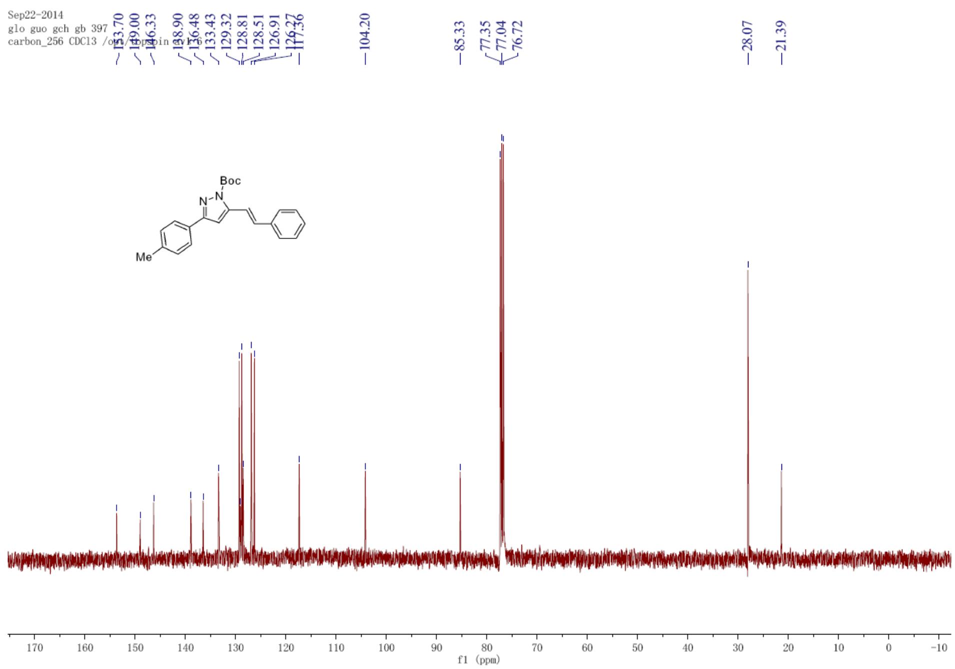
[13]C NMR spectrum of **4gd**



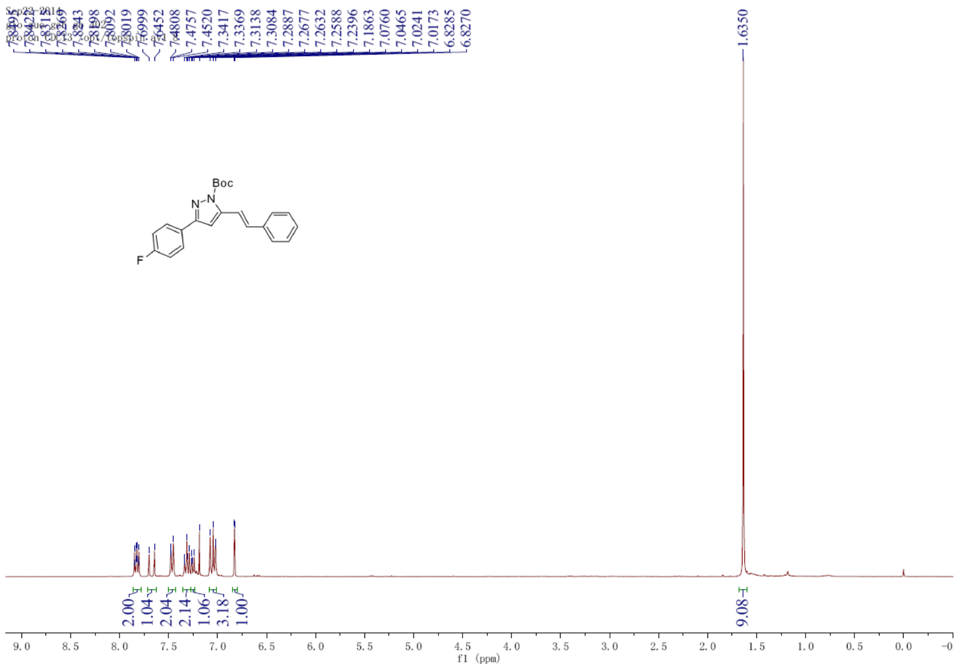
^{1}H NMR spectrum of **4ae**



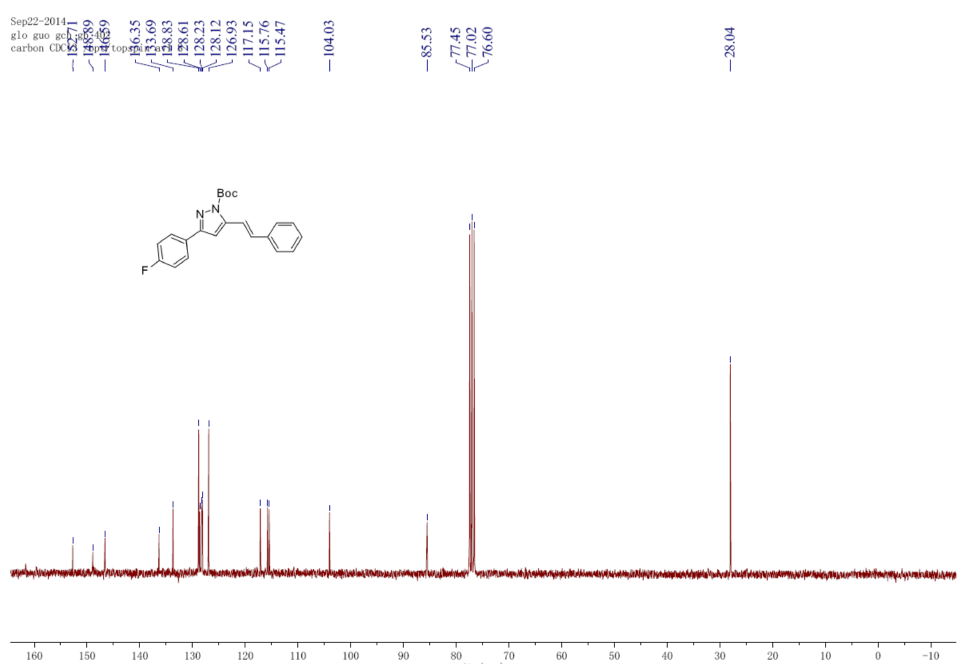
^{13}C NMR spectrum of **4ae**



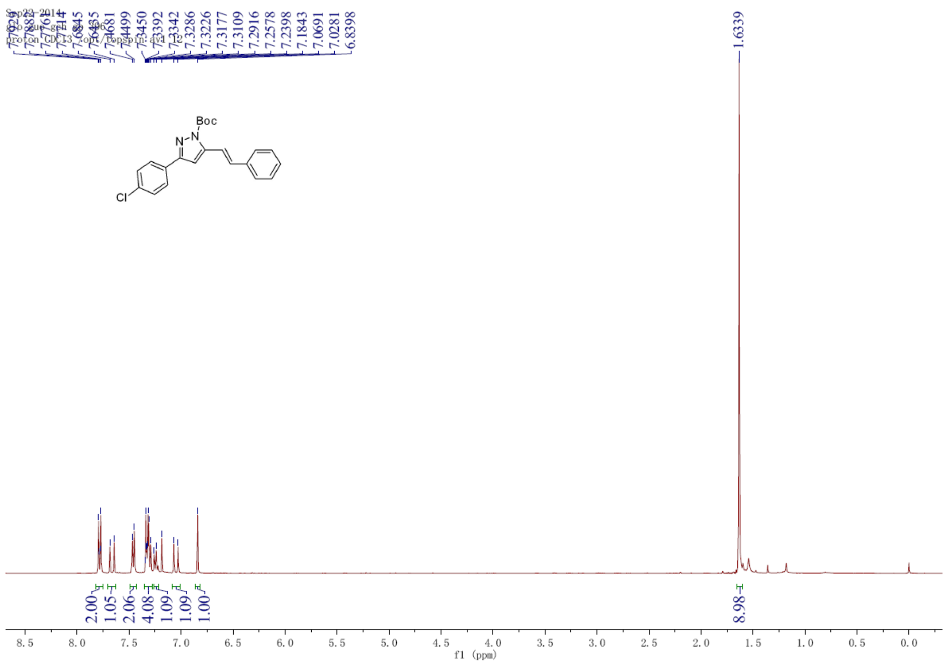
^{1}H NMR spectrum of **4ag**



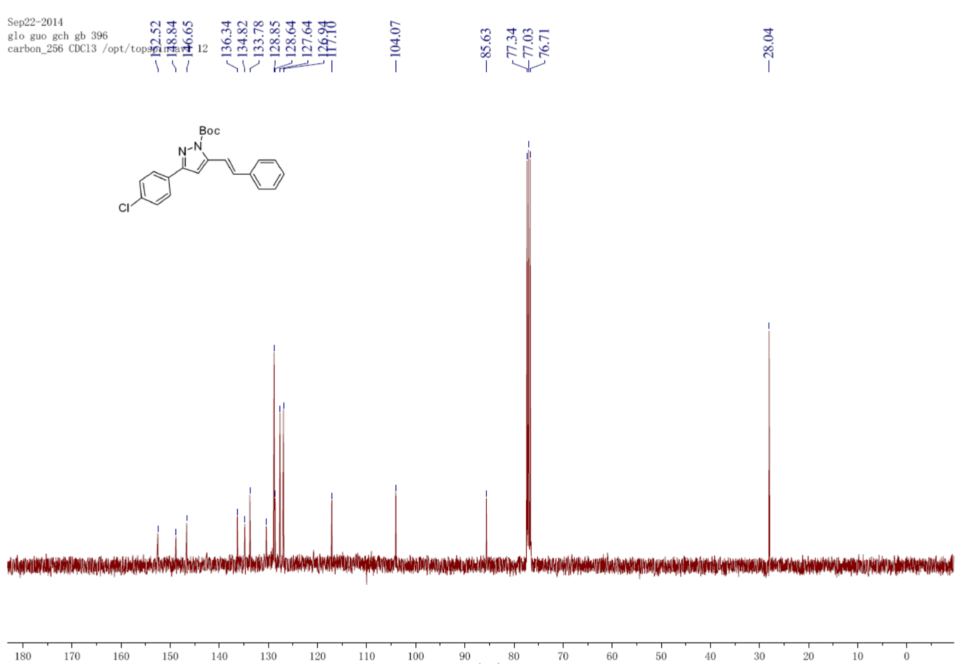
^{13}C NMR spectrum of **4ag**



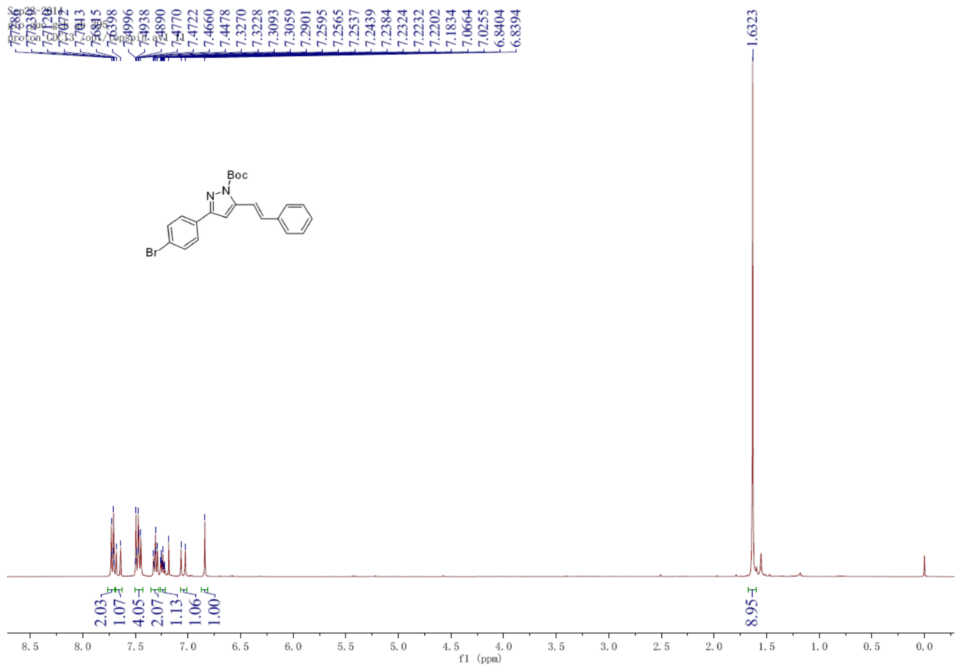
^{1}H NMR spectrum of **4ah**



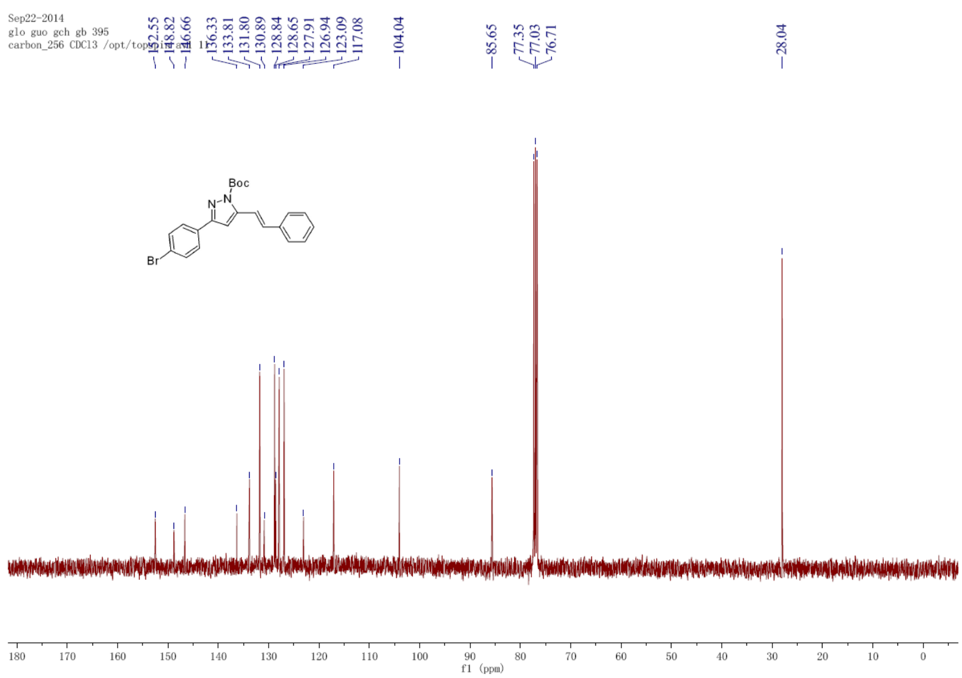
^{13}C NMR spectrum of **4ah**



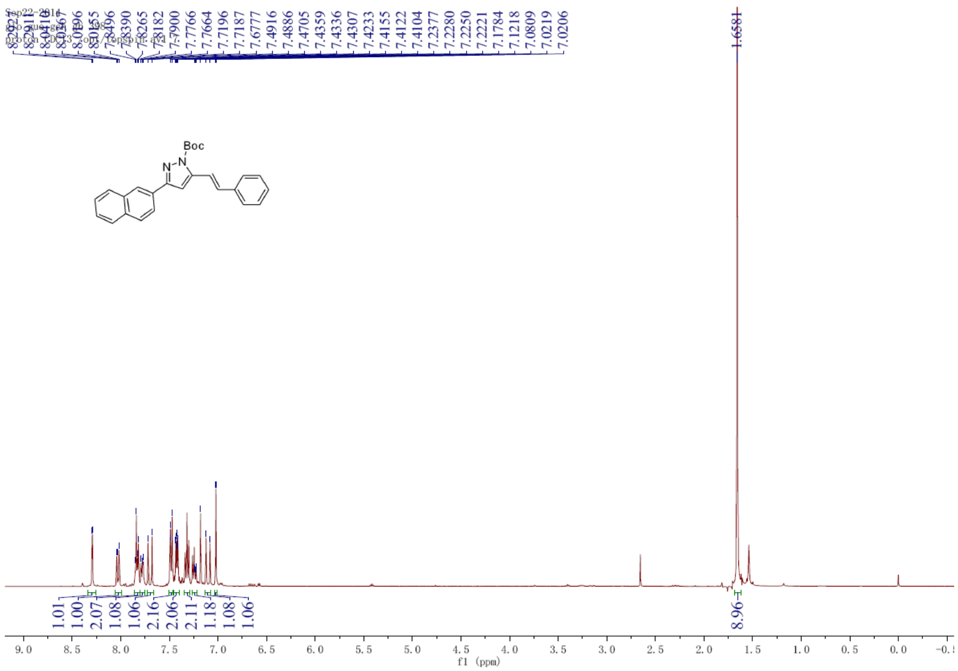
[1]H NMR spectrum of **4ai**



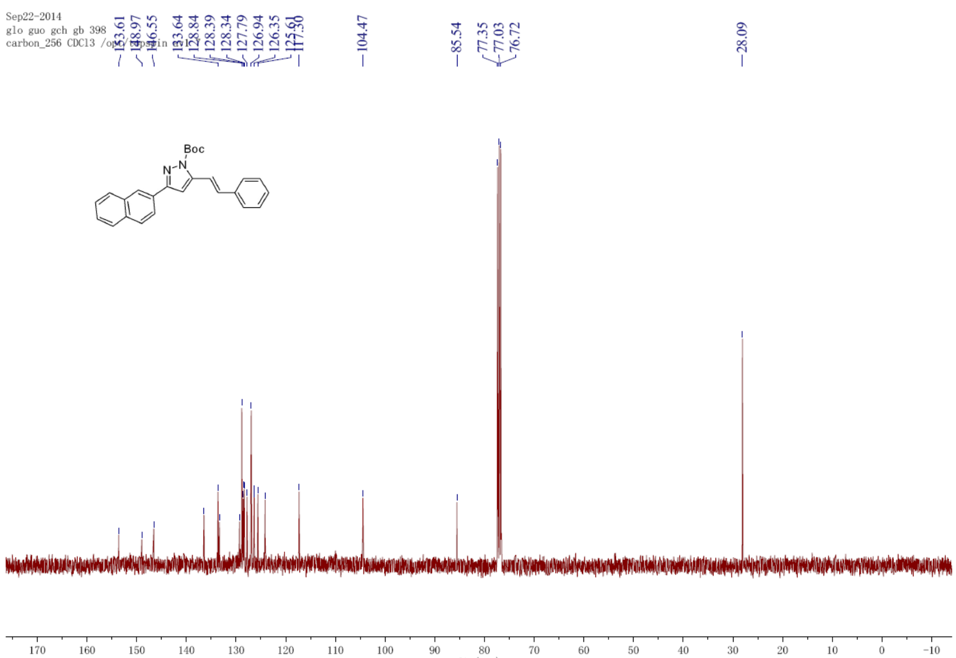
[13]C NMR spectrum of **4ai**



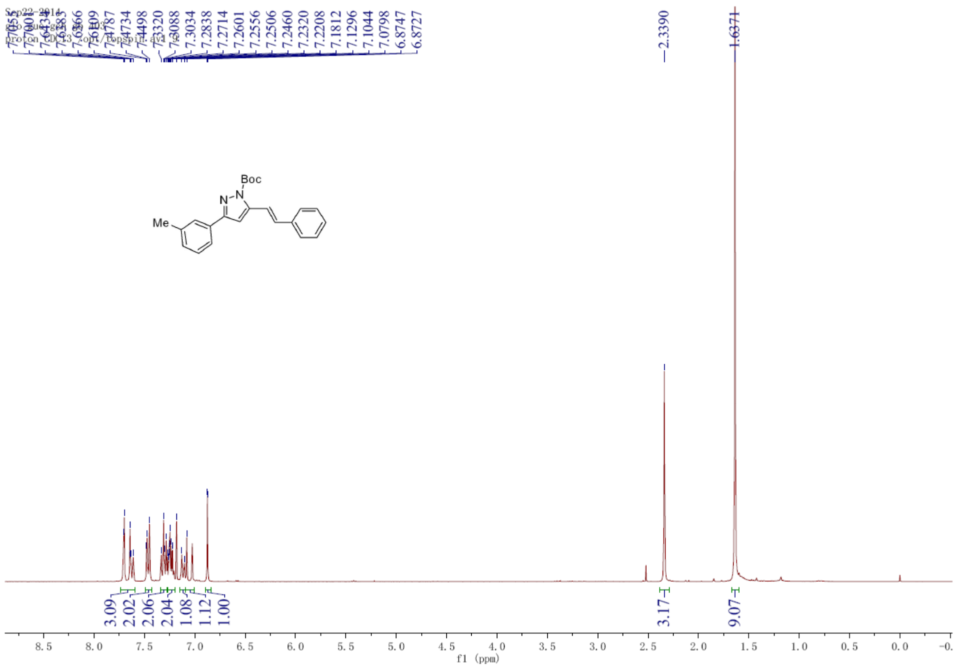
[1]H NMR spectrum of **4ak**



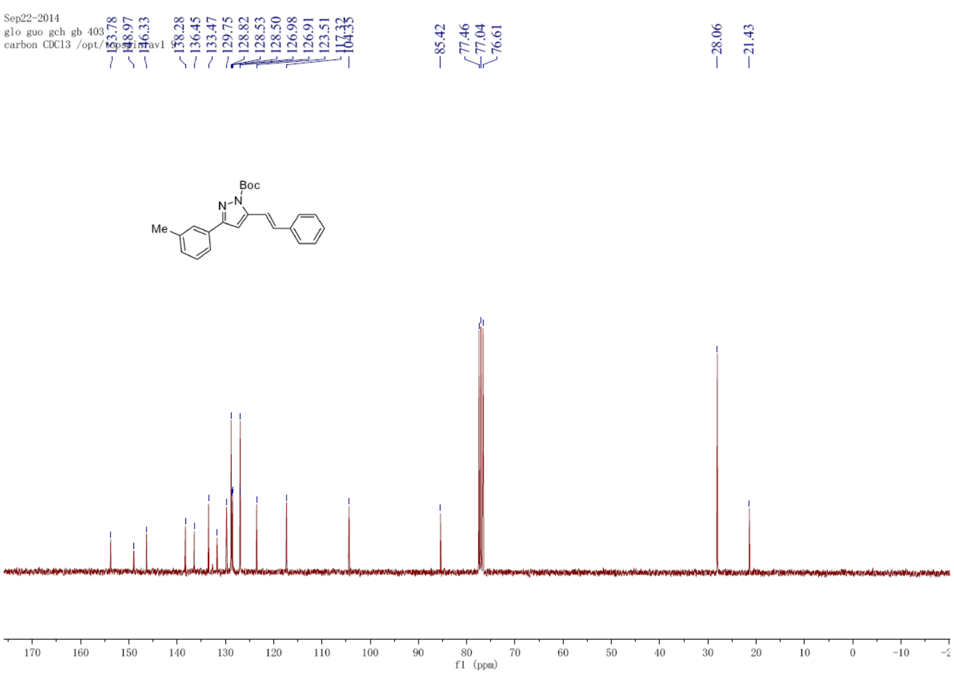
[13]C NMR spectrum of **4ak**



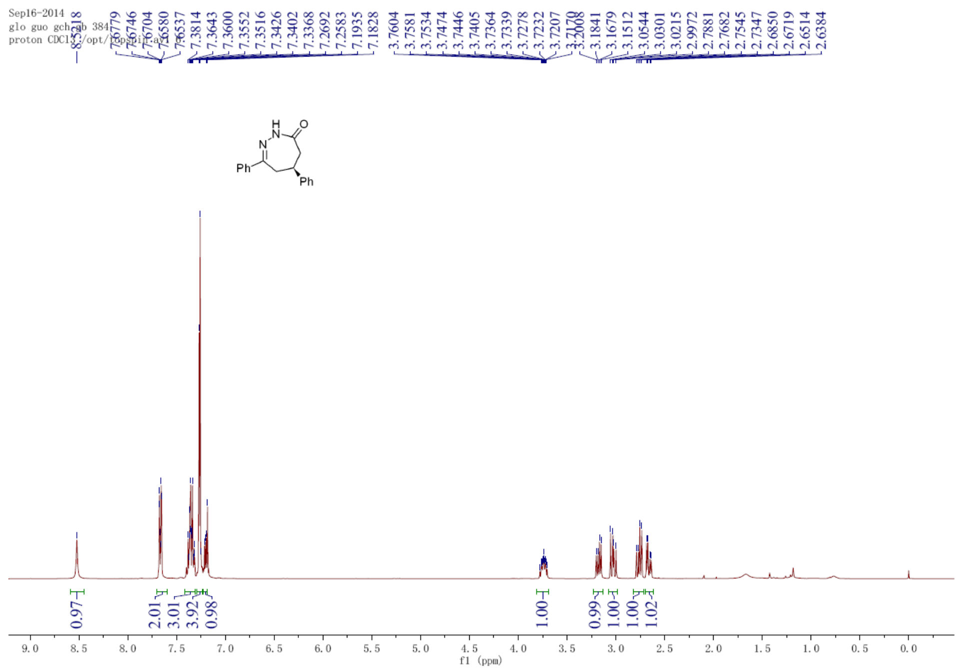
[1]H NMR spectrum of **4am**



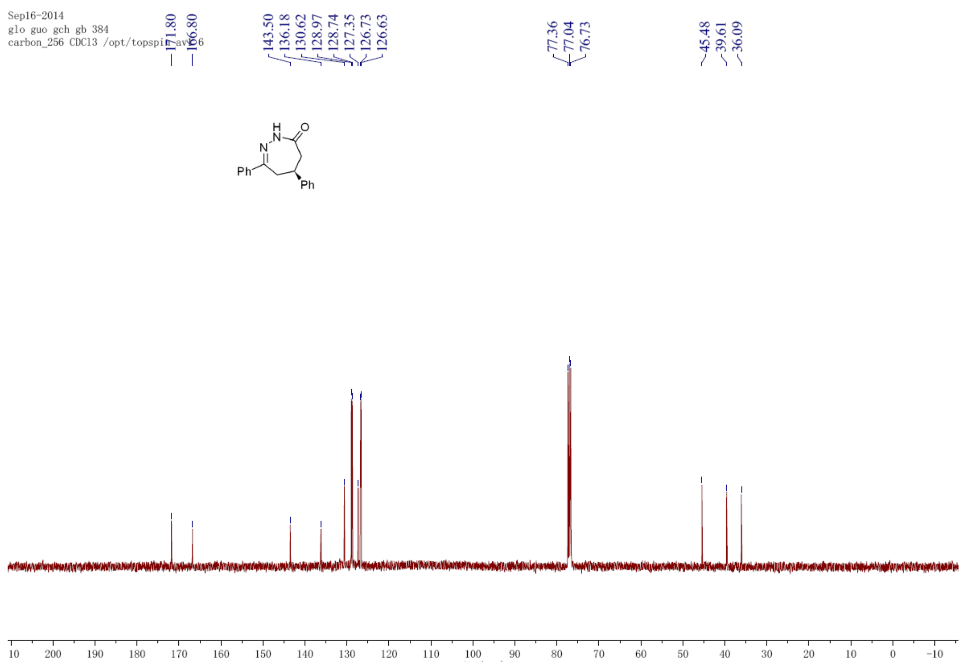
[13]C NMR spectrum of **4am**



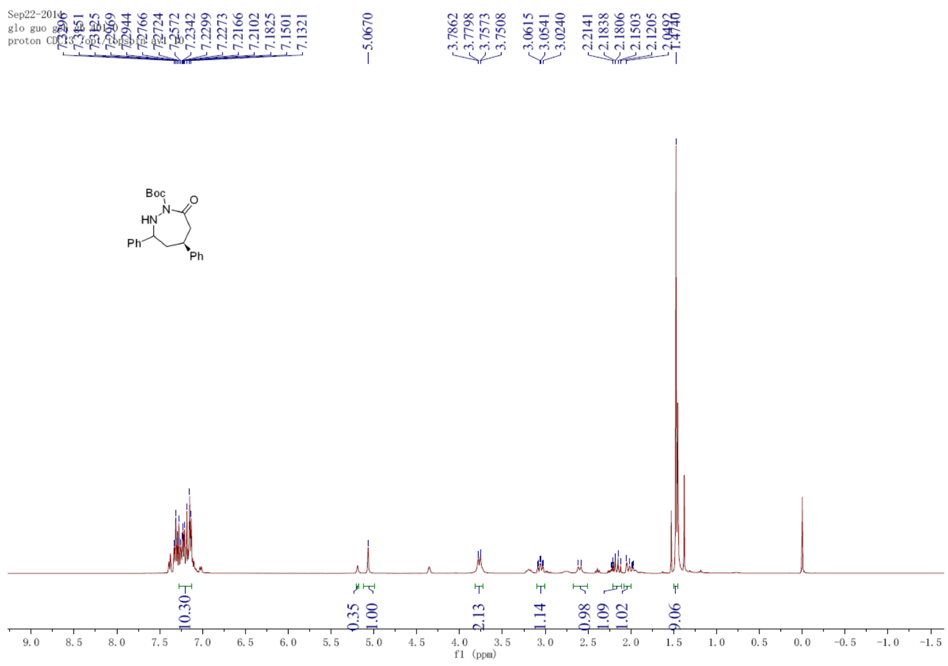
[1]H NMR spectrum of **6**



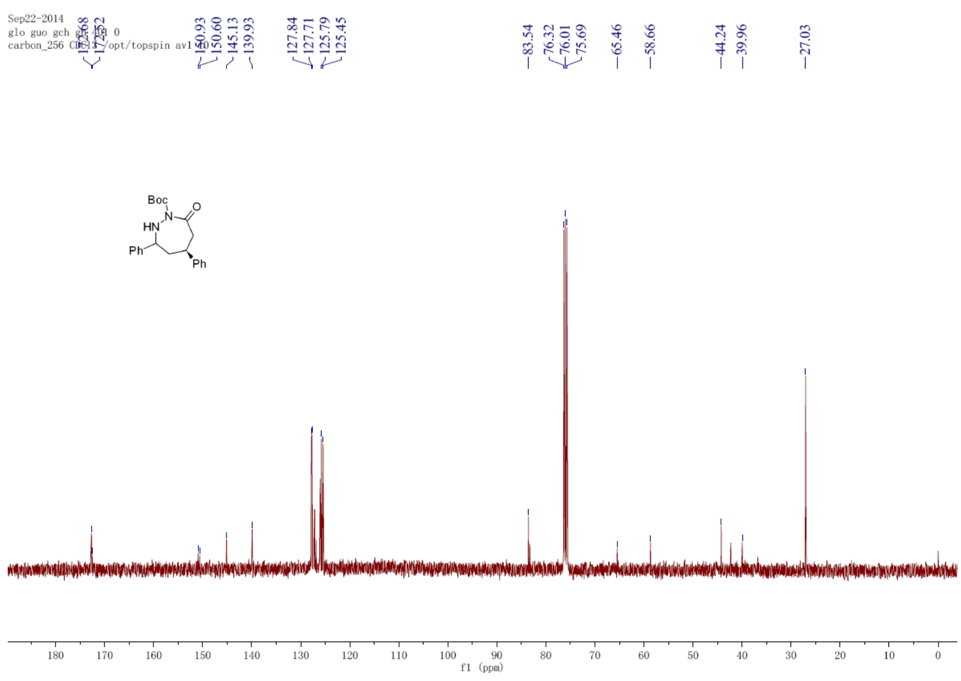
[13]C NMR spectrum of **6**



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

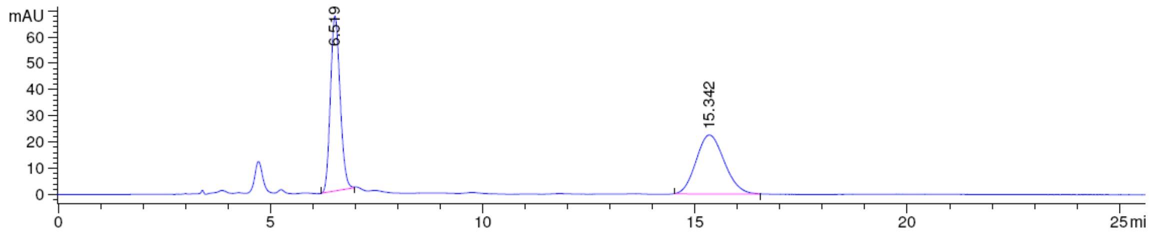


^{13}C NMR spectrum of **7**



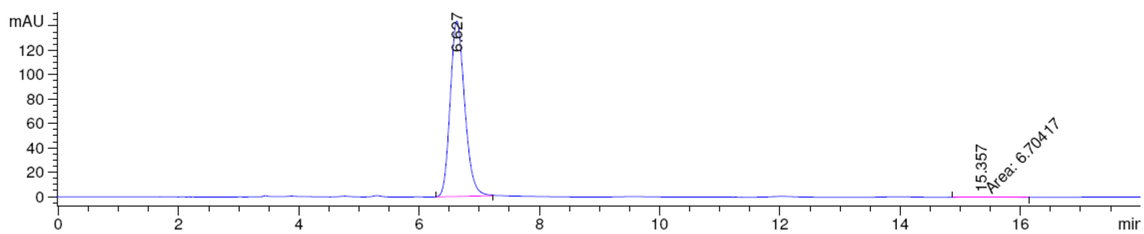
8. HPLC traces

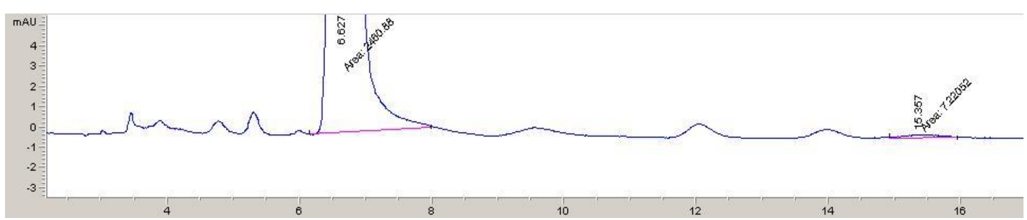
Rac-3ad



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.519	BB	0.2446	1057.58069	66.85200	50.2613
2	15.342	BB	0.6795	1046.58472	22.54806	49.7387
Totals :				2104.16541	89.40006	

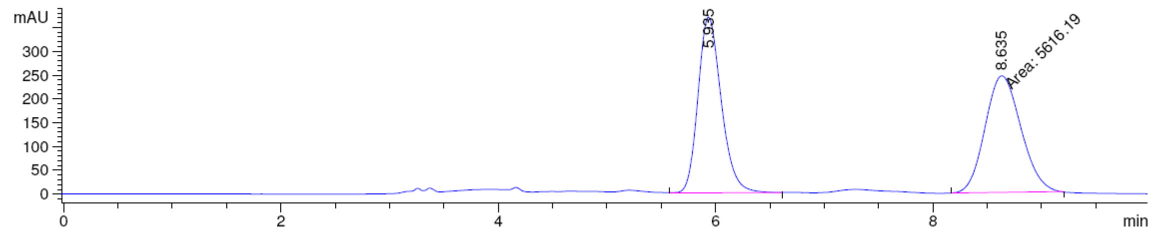
Asy-3ad





Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.627	BB	0.2592	2406.00806	143.78796	99.7221
2	15.357	MM	0.7043	6.70417	1.58648e-1	0.2779
Totals :				2412.71222	143.94661	

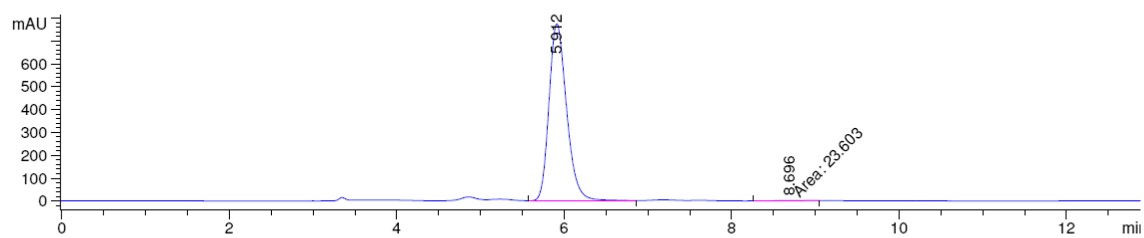
Rac-3bd

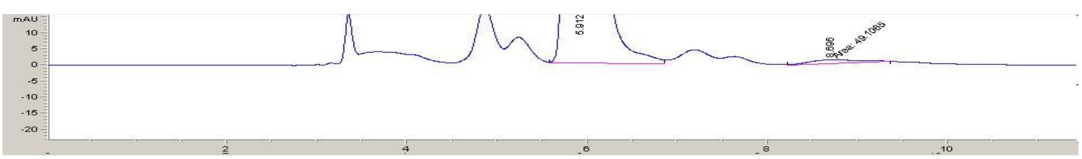


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.935	VB	0.2299	5499.33789	368.92136	49.4744
2	8.635	MM	0.3824	5616.19238	244.80255	50.5256

Totals : 1.11155e4 613.72391

Asy-3bd

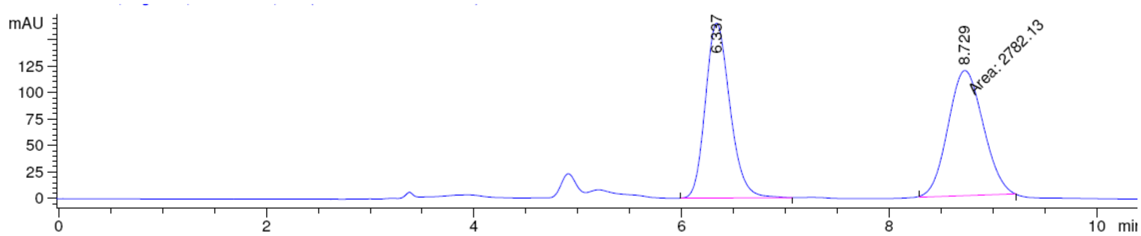




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.912	VB	0.2262	1.13650e4	774.56903	99.7927
2	8.696	MM	0.3539	23.60300	8.16146e-1	0.2073

Totals : 1.13886e4 775.38518

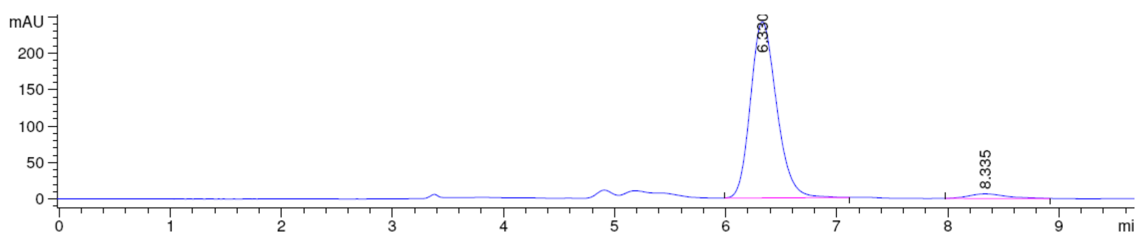
Rac-3cd



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.337	BB	0.2540	2712.96411	164.87769	49.3707
2	8.729	MM	0.3930	2782.12939	117.97935	50.6293

Totals : 5495.09351 282.85704

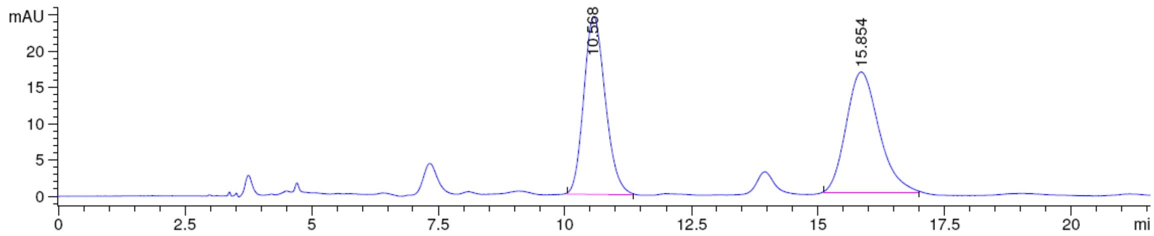
Asy-3cd



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.330	BB	0.2529	3956.56641	241.76892	96.2031
2	8.335	BB	0.3598	156.15468	6.39752	3.7969

Totals : 4112.72108 248.16644

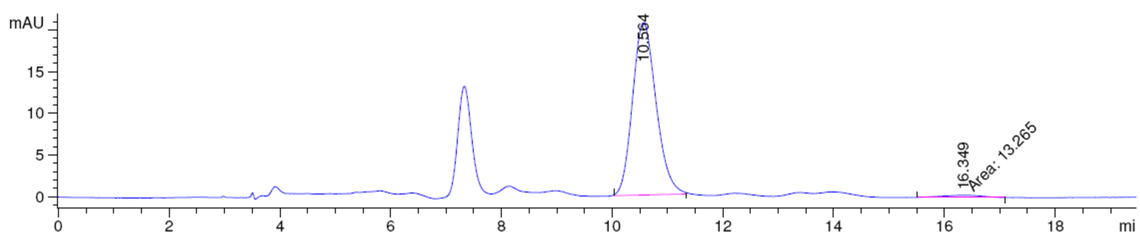
Rac-3dd



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.569	BB	0.4580	1129.25488	38.07580	49.0073
2	15.851	BB	0.6504	1175.00537	26.19232	50.9927

Totals : 2304.26025 64.26812

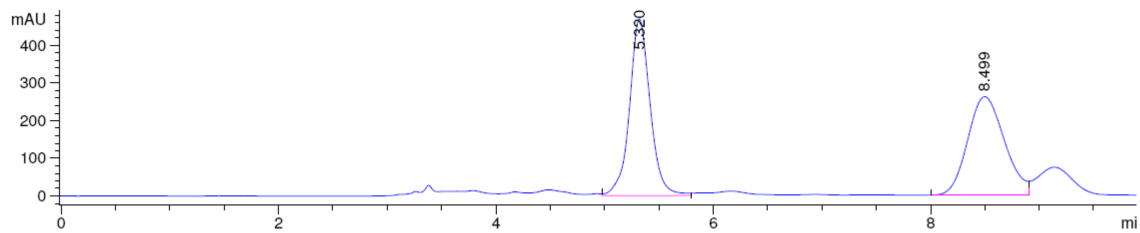
Asy-3dd



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	10.564	BB	0.4383	610.34760	20.67969	97.8729
2	16.349	MM	0.8174	13.26503	2.70487e-1	2.1271

Totals : 623.61263 20.95018

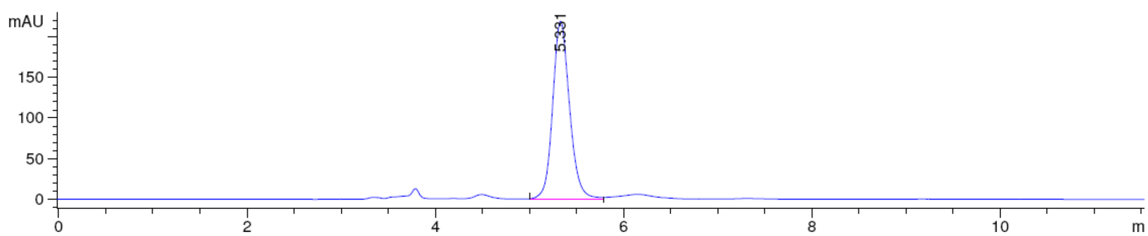
Rac-3ed

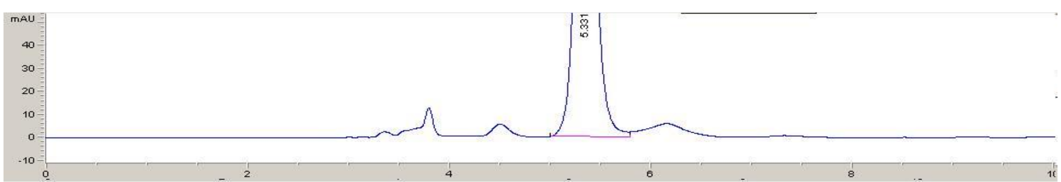


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.320	VB	0.2008	6221.42236	468.78500	50.1925
2	8.499	BV	0.3659	6173.69141	261.97028	49.8075

Totals : 1.23951e4 730.75528

Asy-3ed

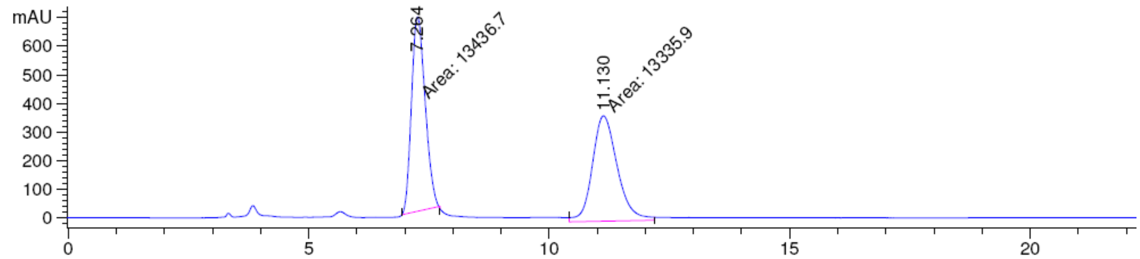




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.331	BB	0.1905	2724.83936	218.41327	100.0000

Totals : 2724.83936 218.41327

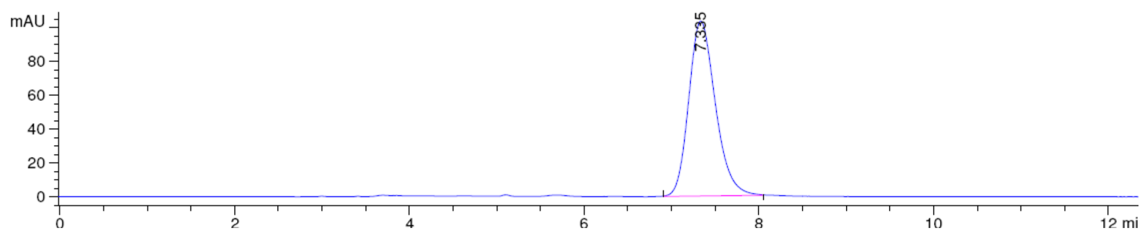
Rac-3fd

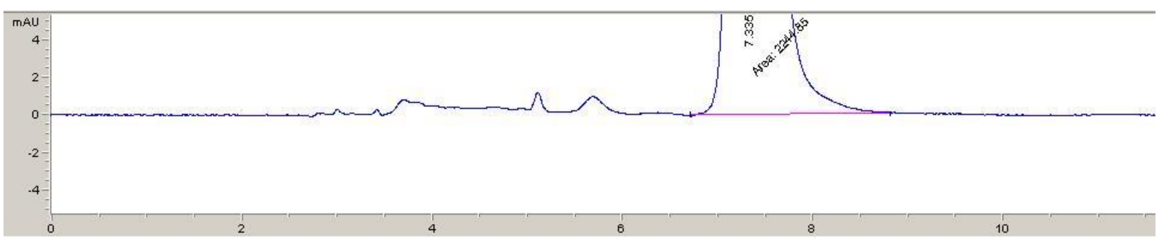


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.264	MM	0.3300	1.34367e4	678.67761	50.1882
2	11.130	MM	0.6038	1.33359e4	368.11630	49.8118

Totals : 2.67727e4 1046.79391

Asy-3fd

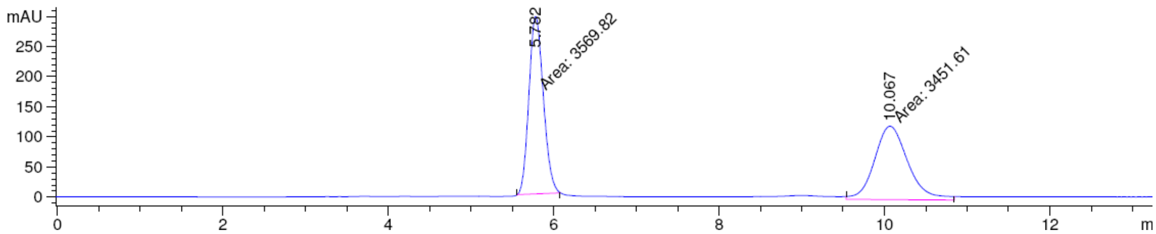




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.335	BB	0.3248	2194.75757	103.32362	100.0000

Totals : 2194.75757 103.32362

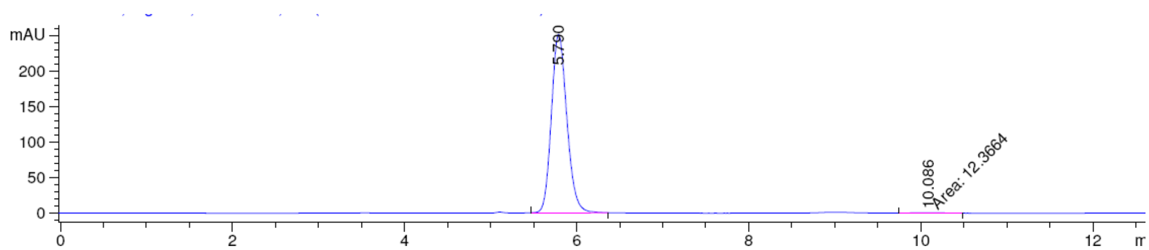
Rac-3gd

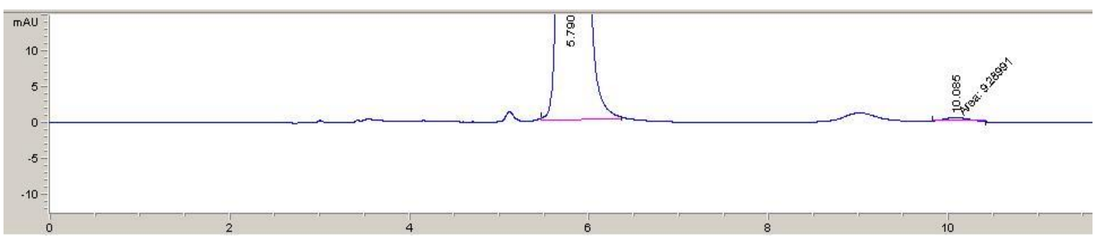


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.782	MM	0.2018	3569.81567	294.78189	50.8418
2	10.067	MM	0.4714	3451.60791	122.02920	49.1582

Totals : 7021.42358 416.81109

Asy-3gd

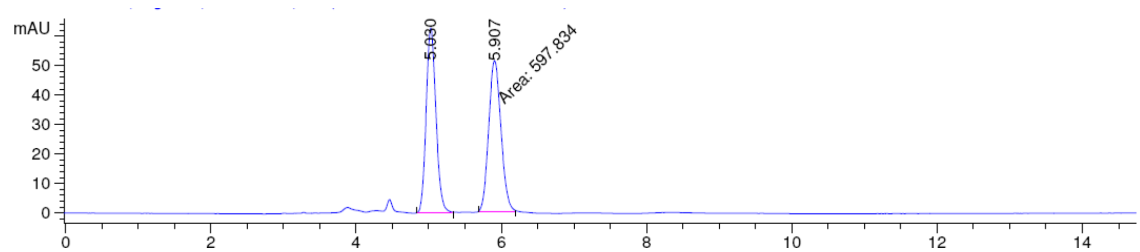




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.790	BB	0.1946	3160.44360	251.50658	99.6102
2	10.086	MM	0.3643	12.36638	5.65741e-1	0.3898

Totals : 3172.80999 252.07232

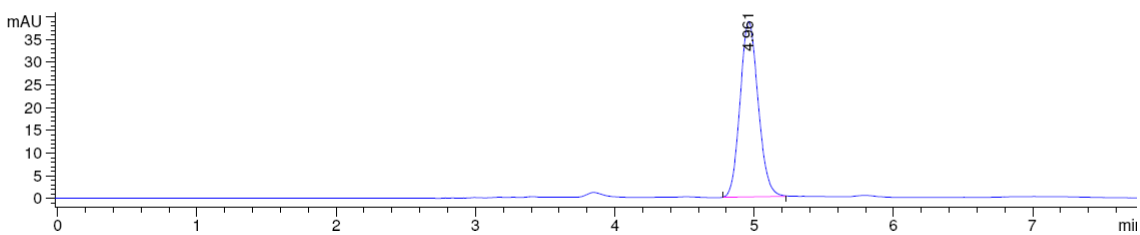
Rac-3hd

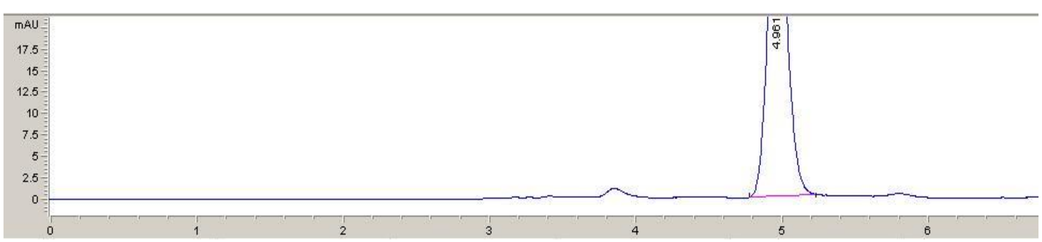


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.030	BB	0.1451	585.11322	62.56184	49.4623
2	5.907	MM	0.1952	597.83429	51.05091	50.5377

Totals : 1182.94751 113.61274

Asy-3hd

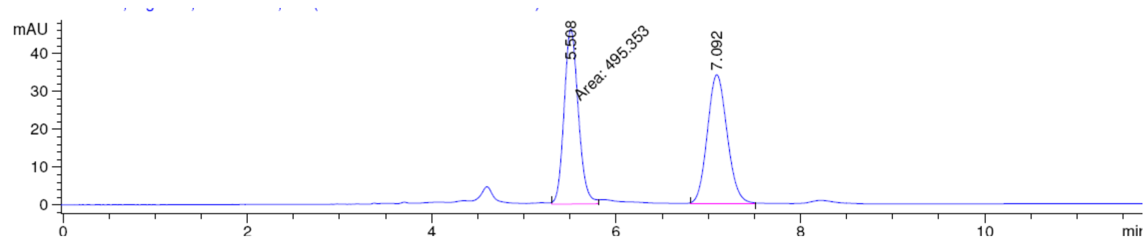




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.961	BB	0.1392	348.61063	38.64572	100.0000

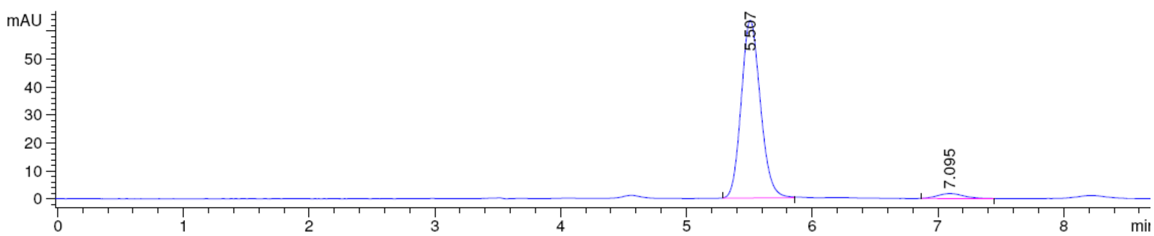
Totals : 348.61063 38.64572

Rac-3id



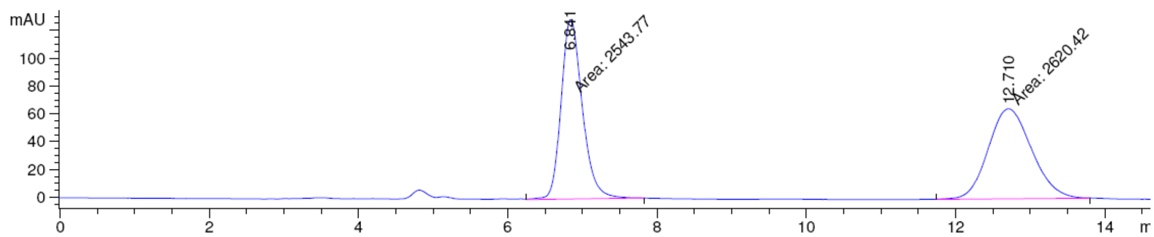
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.508	MM	0.1788	495.35330	46.18275	49.3816
2	7.092	BB	0.2323	507.75891	33.98175	50.6184
Totals :				1003.11221	80.16451	

Asy-3id



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.507	BB	0.1645	672.93549	63.59381	96.2483
2	7.095	BB	0.1846	26.23054	1.79417	3.7517
Totals :				699.16603	65.38798	

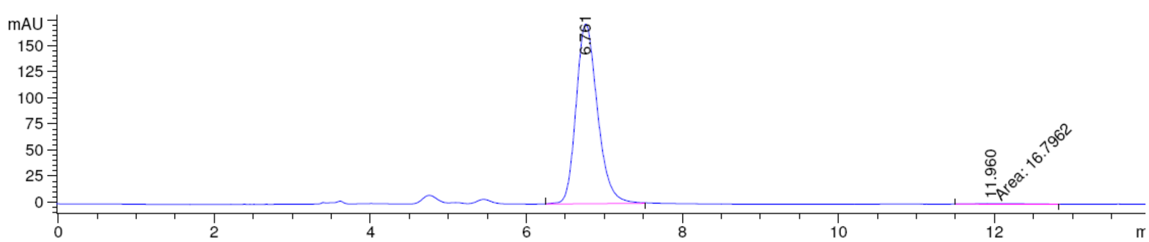
Rac-3ae

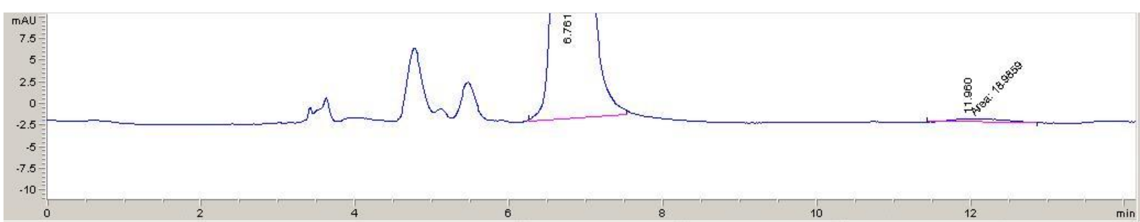


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.841	MM	0.3292	2543.76880	128.78394	49.2579
2	12.710	MM	0.6758	2620.41821	64.62562	50.7421

Totals : 5164.18701 193.40955

Asy-3ae

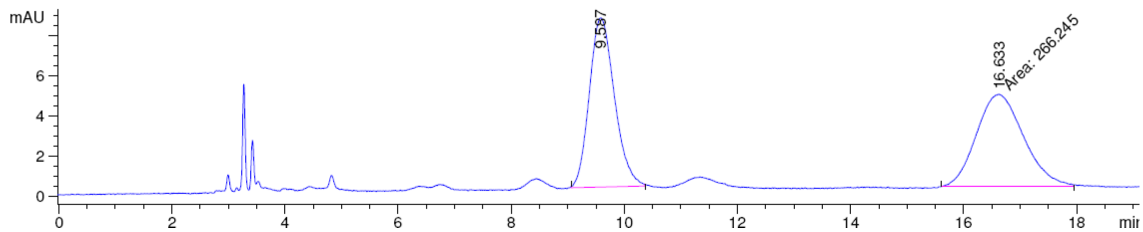




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.761	BB	0.2947	3295.54297	172.68240	99.4929
2	11.960	MM	0.7761	16.79625	3.60699e-1	0.5071

Totals : 3312.33922 173.04310

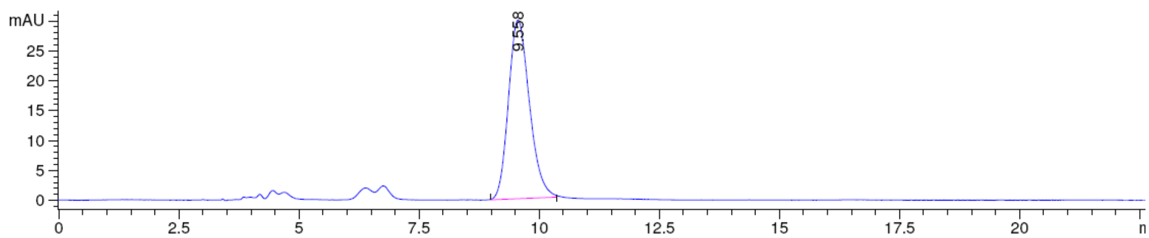
Rac-3af

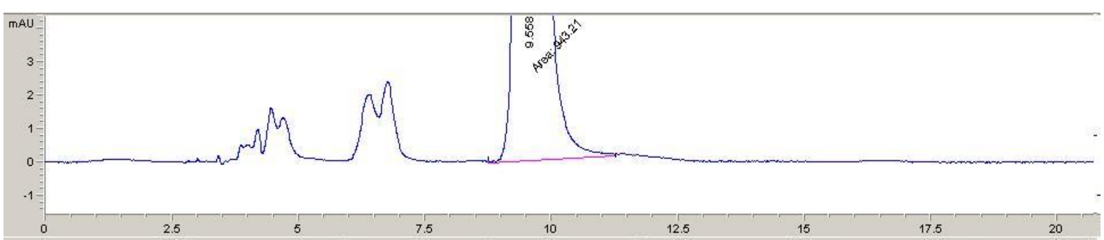


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.587	BB	0.3660	259.67239	8.41628	49.3752
2	16.633	MM	0.9672	266.24475	4.58812	50.6248

Totals : 525.91714 13.00440

Asy-3af

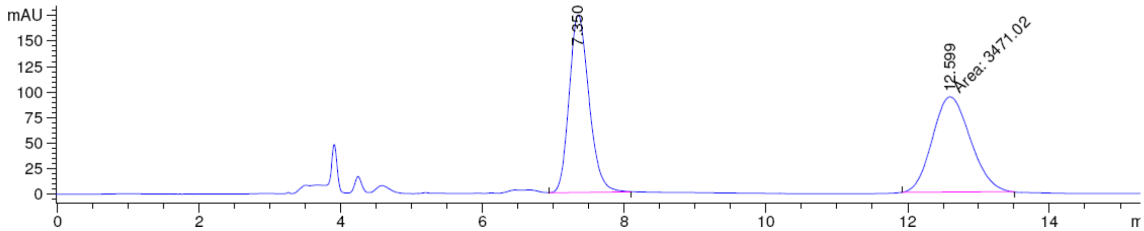




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	9.558	BB	0.4703	907.97192	29.89494	100.0000

Totals : 907.97192 29.89494

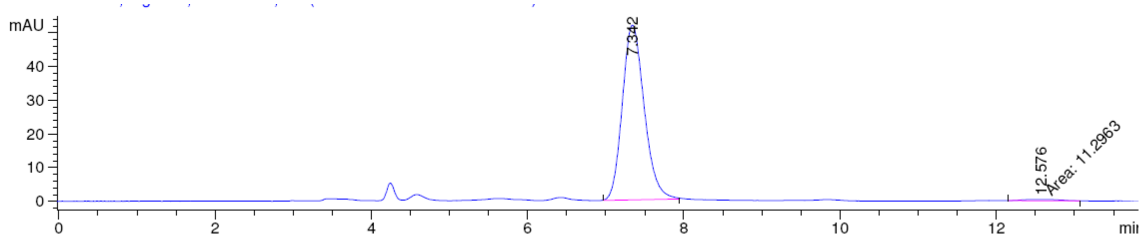
Rac-3ag



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.350	VB	0.3002	3383.93091	173.76974	49.3648
2	12.599	MM	0.6212	3471.01636	93.12990	50.6352

Totals : 6854.94727 266.89964

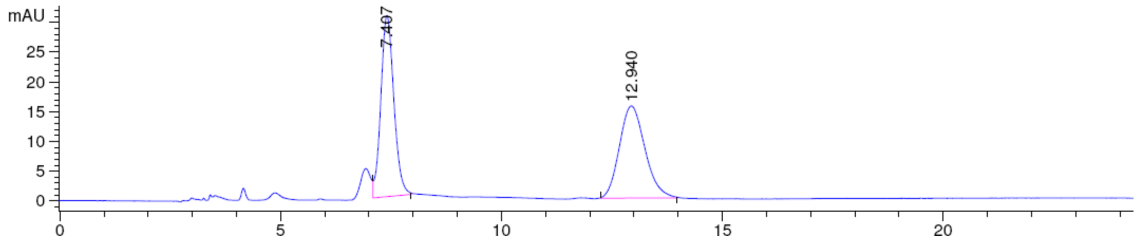
Asy-3ag



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.342	BB	0.2992	1010.32361	51.87300	98.8943
2	12.576	MM	0.4747	11.29630	3.96644e-1	1.1057

Totals : 1021.61991 52.26964

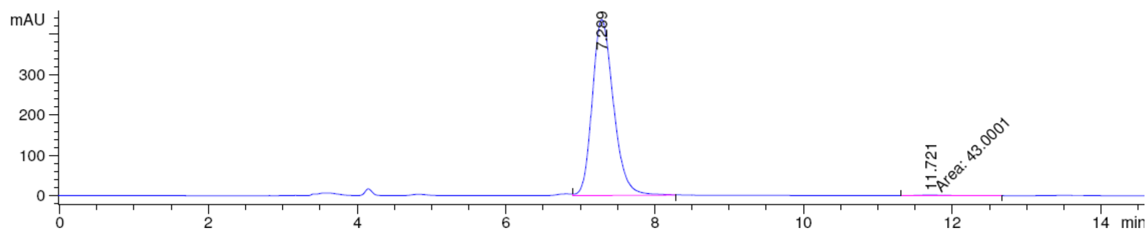
Rac-3ah

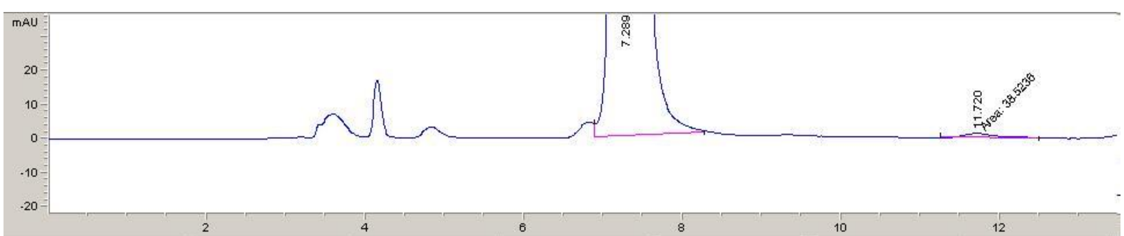


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.407	VB	0.3139	624.24194	30.48642	50.0897
2	12.940	BB	0.6065	622.00671	15.48974	49.9103

Totals : 1246.24866 45.97616

Asy-3ah

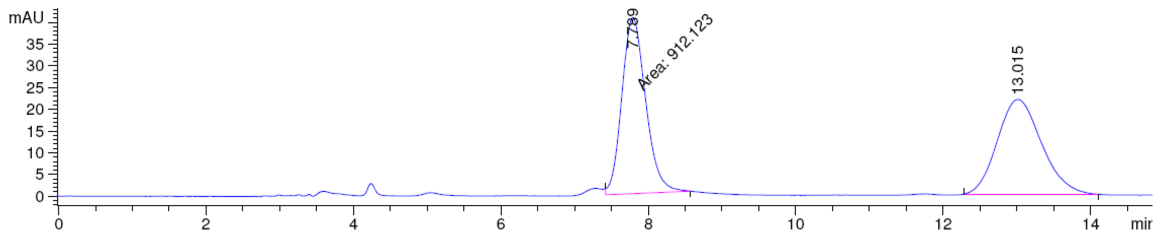




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.289	VB	0.3052	8630.07617	435.42636	99.5042
2	11.721	MM	0.5410	43.00012	1.32483	0.4958

Totals : 8673.07629 436.75119

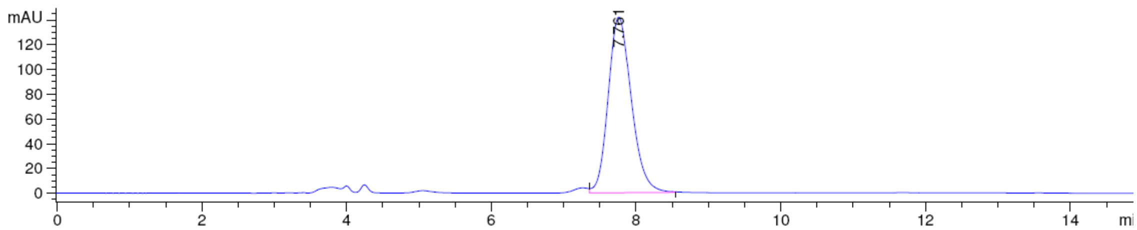
Rac-3ai

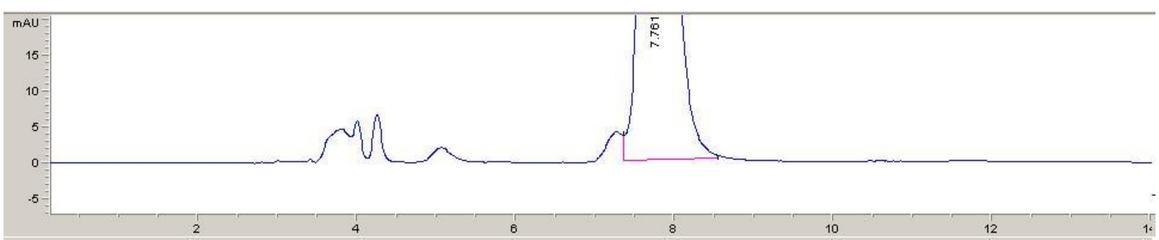


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.789	MM	0.3745	912.12292	40.59372	49.7293
2	13.015	BB	0.6289	922.05469	21.91245	50.2707

Totals : 1834.17761 62.50617

Asy-3ai

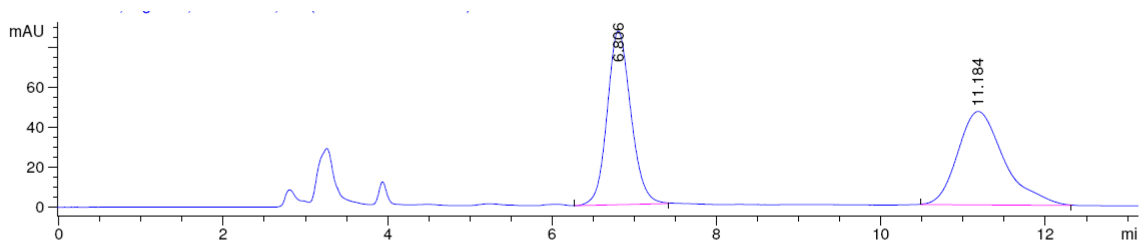




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.761	VB	0.3435	3154.67432	141.84454	100.0000

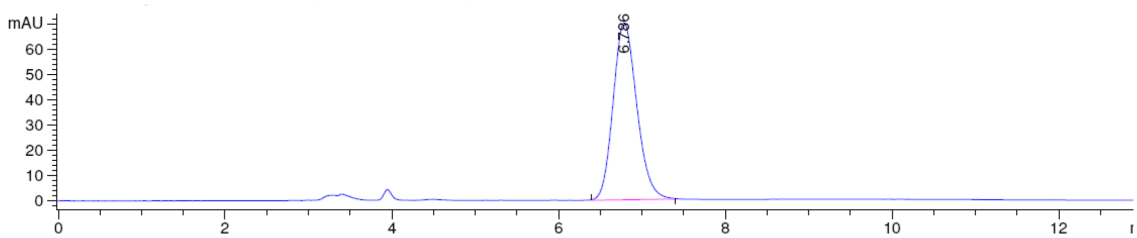
Totals : 3154.67432 141.84454

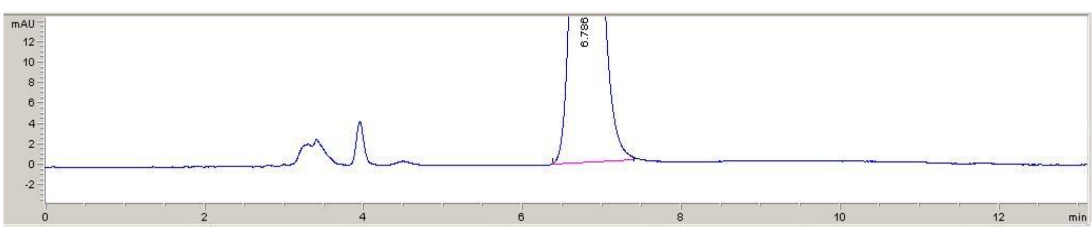
Rac-3aj



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.806	BB	0.3083	1938.12451	97.32986	49.1794
2	11.185	BB	0.5730	2002.80701	52.97967	50.8206
Totals :				3940.93152	150.30952	

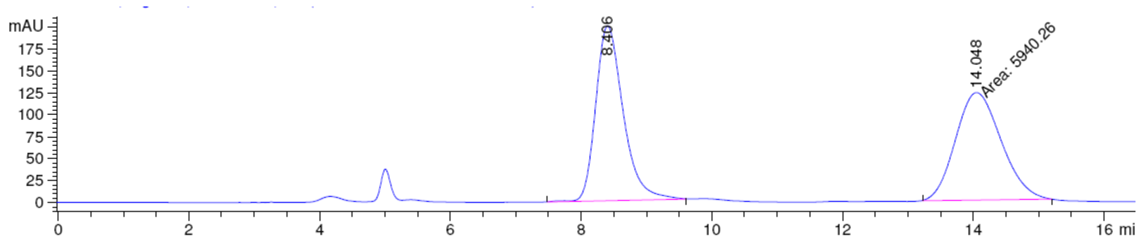
Asy-3aj





Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.786	BB	0.3045	1386.40991	70.17199	100.0000
Totals :				1386.40991	70.17199	

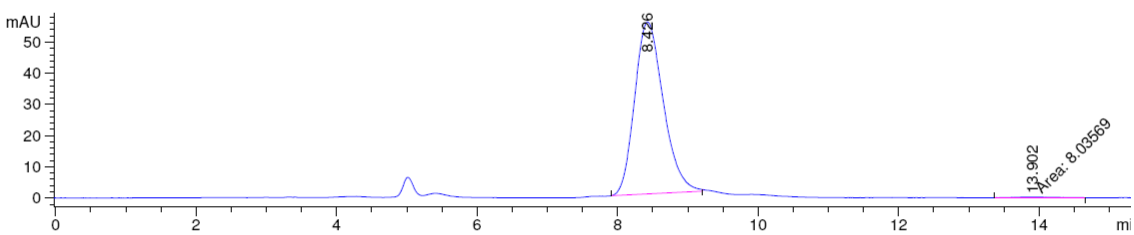
Rac-3ak

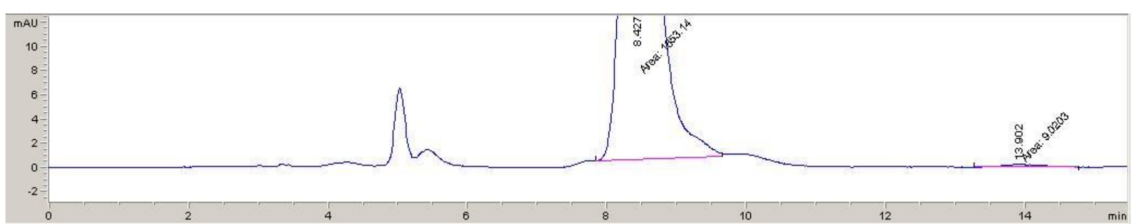


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.406	BB	0.4453	5828.34326	199.20988	49.5245
2	14.048	MM	0.8089	5940.26416	122.39760	50.4755

Totals :				1.17686e4	321.60748	

Asy-3ak

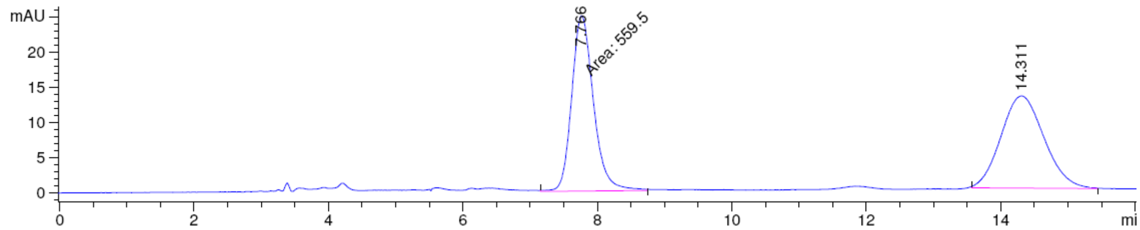




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.426	BB	0.4339	1563.86292	55.13797	99.4888
2	13.902	MM	0.6622	8.03569	2.02237e-1	0.5112

Totals :				1571.89860	55.34020	

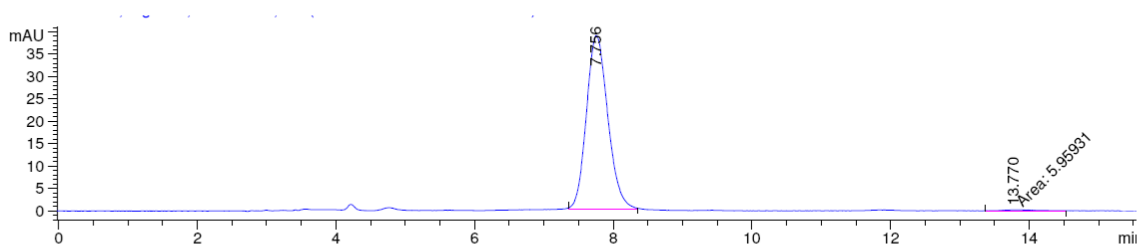
Rac-3al

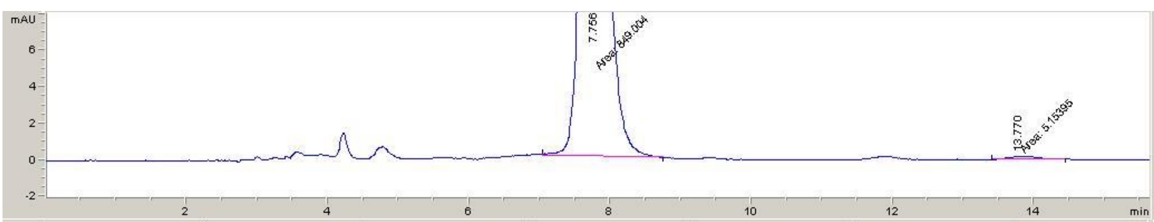


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.766	MM	0.3754	559.49969	24.84038	49.0382
2	14.311	BB	0.5671	581.44635	13.04160	50.9618

Totals : 1140.94604 37.88198

Asy-3al

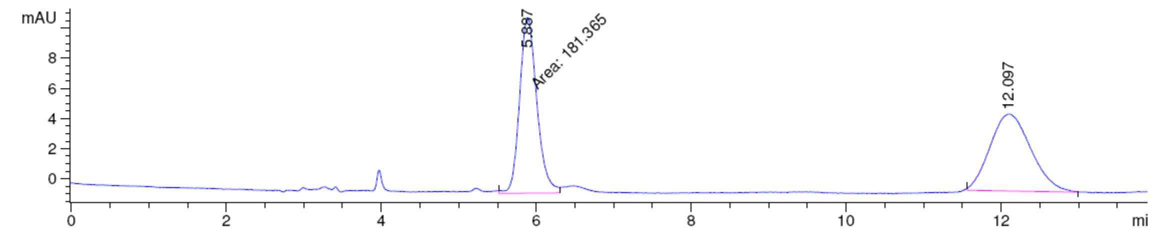




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.756	BB	0.3312	830.96478	38.74724	99.2880
2	13.770	MM	0.5221	5.95931	1.90237e-1	0.7120

Totals : 836.92410 38.93748

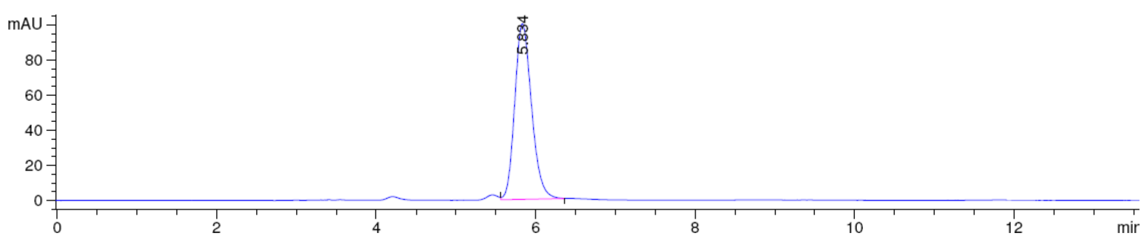
Rac-3am

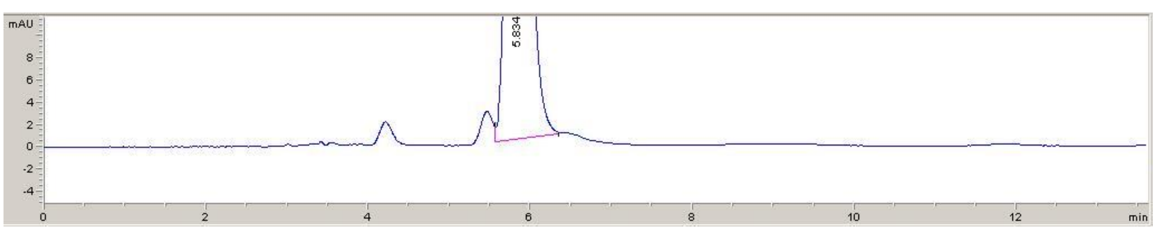


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.887	MM	0.2588	181.36459	11.67959	49.1788
2	12.097	BB	0.4356	187.42157	5.11334	50.8212

Totals : 368.78616 16.79293

Asy-3am

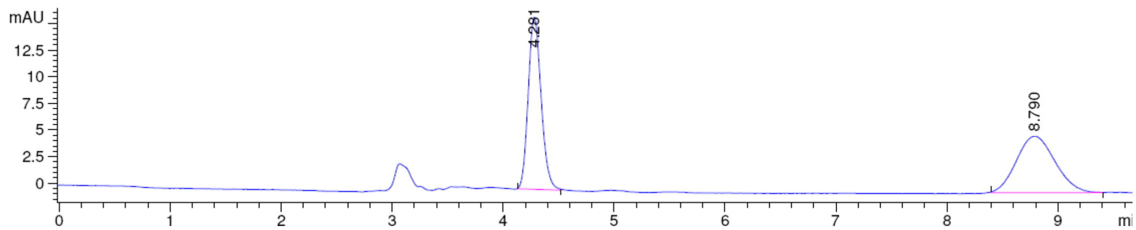




Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.834	VB	0.2263	1467.37708	99.93972	100.0000

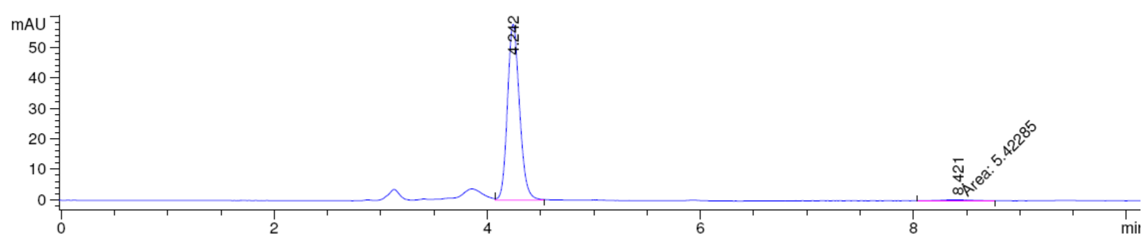
Totals : 1467.37708 99.93972

Rac-3an



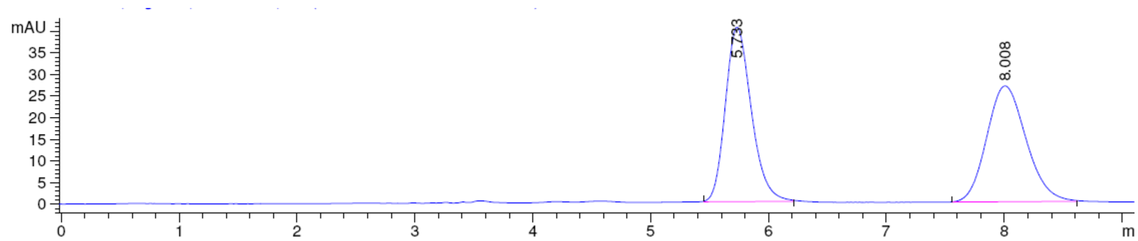
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.281	BB	0.1245	131.00998	16.18060	50.5374
2	8.790	BB	0.3724	128.22386	5.31565	49.4626
Totals :				259.23384	21.49626	

Asy-3an



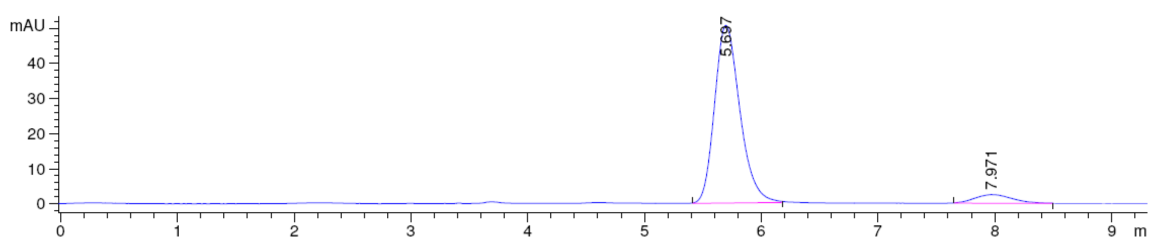
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.242	VB	0.1211	455.86874	57.77176	98.8244
2	8.421	MM	0.3636	5.42285	2.48561e-1	1.1756
Totals :				461.29160	58.02032	

Rac-3ao



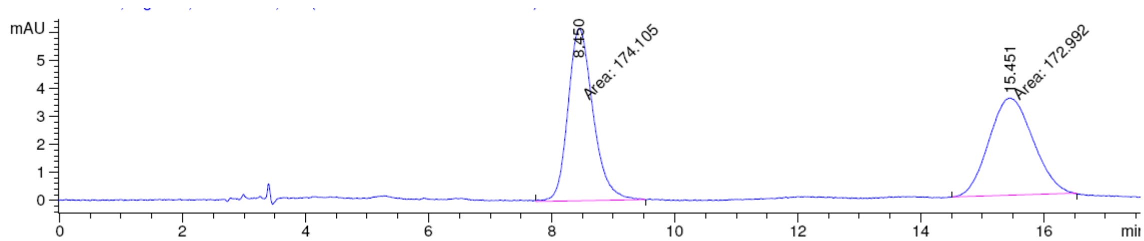
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.733	BB	0.2357	617.60510	40.32320	49.8664
2	8.008	BB	0.3566	620.91364	26.76661	50.1336
Totals :				1238.51874	67.08981	

Asy-3ao



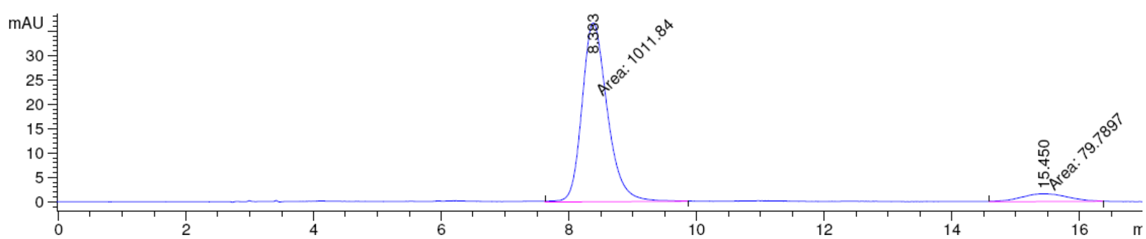
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.697	BB	0.2317	762.00671	50.60434	93.2208
2	7.971	BB	0.2699	55.41455	2.48703	6.7792
Totals :				817.42127	53.09137	

Rac-3ap



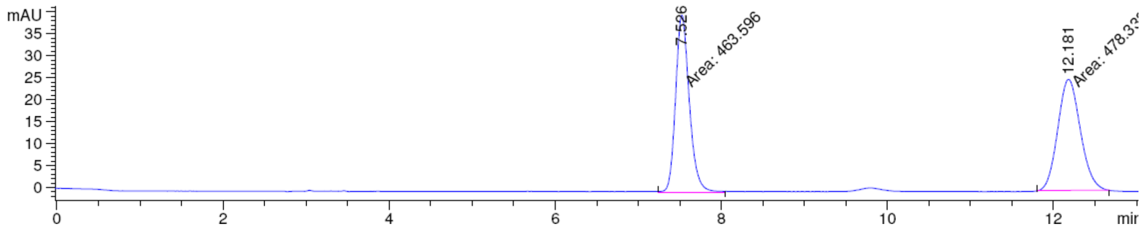
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.450	MM	0.4699	174.10521	6.17553	50.1604
2	15.451	MM	0.8290	172.99203	3.47783	49.8396
Totals :				347.09724	9.65336	

Asy-3ap



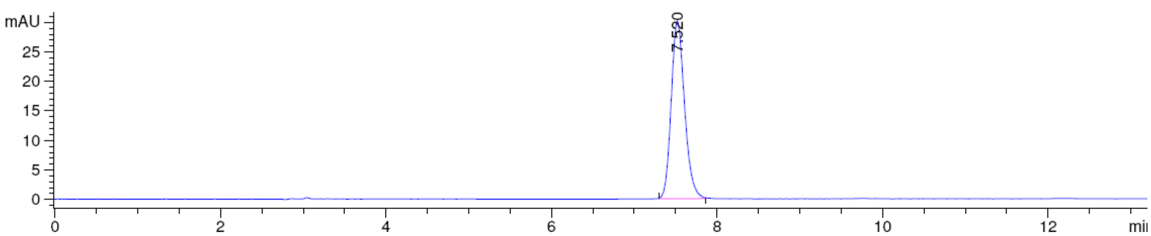
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	8.383	MM	0.4597	1011.84161	36.68555	92.6908
2	15.450	MM	0.8265	79.78970	1.60906	7.3092
Totals :				1091.63132	38.29461	

Rac-6



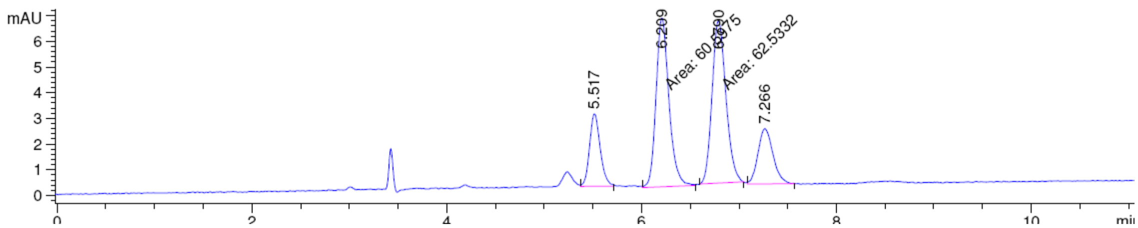
Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.526	MM	0.1916	463.59552	40.32530	49.2174
2	12.181	MM	0.3150	478.33774	25.30543	50.7826
Totals :				941.93326	65.63072	

Asy-6



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	7.520	BB	0.1712	338.57968	30.11347	100.0000
Totals :				338.57968	30.11347	

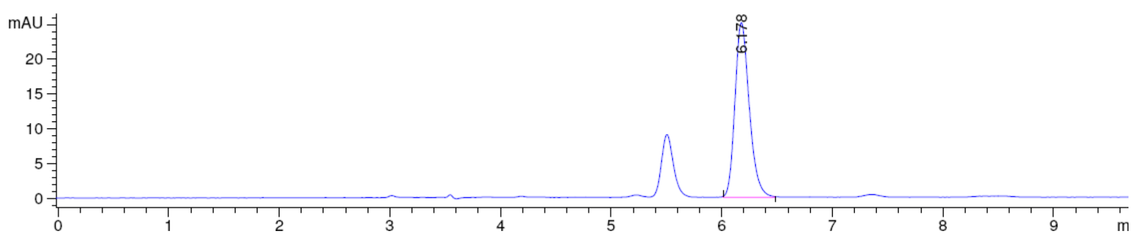
Rac-7



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.517	VB	0.1182	21.56606	2.82091	12.8487
2	6.209	MM	0.1539	60.59749	6.56138	36.1029
3	6.790	MM	0.1649	62.53324	6.32142	37.2562
4	7.266	BB	0.1624	23.14977	2.15295	13.7922

Totals : 167.84656 17.85665

Asy-7



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.178	BB	0.1382	226.54669	25.13174	100.0000

Totals : 226.54669 25.13174