Asymmetric Synthesis of Heteroaryl Atropisomers via a Chiral Gold-Catalyzed Cycloisomerization/Amination Cascade

Rui Guo,[a] Kang-Nan Li, [a] Bin Liu, [a] Hua-Jie Zhu*, [b] Yu-Meng Fan, [a] Liu-Zhu Gong* [a]

[a] *Hefei National Laboratory for Physical Sciences at the Microscale and Department of Chemistry, University of Science and Technology of China, Hefei, Anhui 230026, China.*

[b] *Chinese Centre for Chirality, Key Laboratory of Medicinal Chemistry and Molecular Diagnostics of Education Administration of China Department of Chemistry and Environmental Engineering, Hebei University, Baoding, Hebei 071002, China.*

Supporting Information

Table of contents

General Information……..…….…….……...S2
Part I Experimental Part…….……..…..……S2
Synthesis of the boronic acids **1a-1m**…….……..……...……..…..…….....S2
Synthesis of azodicarboxylate esters **2a-2g**…….……..…..……..…..…….....S4
Screening ligands and solvents……..……..…....S5
Asymmetric synthesis of **4a-4t**……..……..……...…..…S5
Part II Copies of NMR Spectra of compounds……..……...……..……....…....S13
Part III Copies of HPLC Spectra of compounds…….…….…..…….....…..S48
Part IV Barriers to racemization of **4g**……..……...S68
Part V Crystal data and structure refinement for **4t**…….…..…….……..…..S71
Part VI VCD for the absolute configuration determination of **4t**…….....S72
Part VII References…….……..…….……....S73

General method. NMR spectra were recorded on a Brucker-400 MHz spectrometer. ESIMS spectra were recorded on BioTOF Q. Infrared spectra were recorded on a Nicolet MX-1E FT-IR spectrometer. Optical rotations were determined at 589 nm (sodium D line) by using a Perkin-Elmer-343 polarimeter. HPLC analysis was performed on Waters-Breeze (2487 Dual λ Absorbance Detector and 1525 Binary HPLC Pump, UV detection monitored at 254 nm) and Angilent 1200 series. All chiral columns were purchased from Daicel Chemical Industries, LTD. Toluene, diethyl ether and tetrahydrofuran were dried over Na and distilled prior to use. Dichloromethane and dichloroethane were dried over CaH_2 and distilled prior to use. All starting materials were purchased from Alfa and Aldrich and used directly.

Part I Experimental Part

Synthesis of 1a-1m

Compounds **1a** and **1j** have been reported,[1] and the analytical data of which was matched with those reported in the literatures. Compounds **1b-1i** and **1k-1m** were prepared following the known procedure.[1, 2]

(2-(pent-1-yn-1-yl)phenyl)boronic acid (1b). Yield: 75% (0.32 g, two steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Light yellow solid. ^{1}H NMR (400 MHz, acetone-d_6) δ = 7.91 (dd, *J* = 7.4, 0.8 Hz, 1H), 7.38-7.45 (m, 2H), 7.34 (td, *J* = 7.3, 1.7 Hz, 1H), 7.12 (s, 2H), 2.48 (t, *J* = 7.0 Hz, 2H), 1.70-1.56 (m, 2H), 1.05 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 135.91, 133.22, 131.02, 128.23, 94.88, 82.62, 22.80, 21.73, 13.80.

(2-(hept-1-yn-1-yl)phenyl)boronic acid (1c). Yield: 63% (0.46 g, two steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Light yellow solid. ^{1}H NMR (400 MHz, CD_3OD) δ 7.40-7.17 (m, 4H), 2.40 (t, *J* = 6.8 Hz, 2H), 1.67-1.54 (m, 2H), 1.53-1.43 (m, 2H), 1.41-1.36 (m, 2H), 0.95 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, CD_3OD) δ 132.12, 132.06, 129.57, 128.09, 127.41, 91.85, 82.17, 32.11, 29.62, 23.34, 19.94, 14.36.

(2-(oct-1-yn-1-yl)phenyl)boronic acid (1d). Yield: 67% (0.28 g, two steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, CD_3OD) δ 7.37-7.22 (m, 4H), 2.41 (t, *J* = 6.8 Hz, 2H), 1.66-1.54 (m, 2H), 1.54-1.43 (m, 2H), 1.41-1.26 (m, 4H), 0.93 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (101 MHz, CD_3OD) δ 132.13, 132.07, 129.57, 128.09, 127.42, 91.85, 82.17, 32.62, 29.90, 29.59, 23.69, 19.98, 14.43.

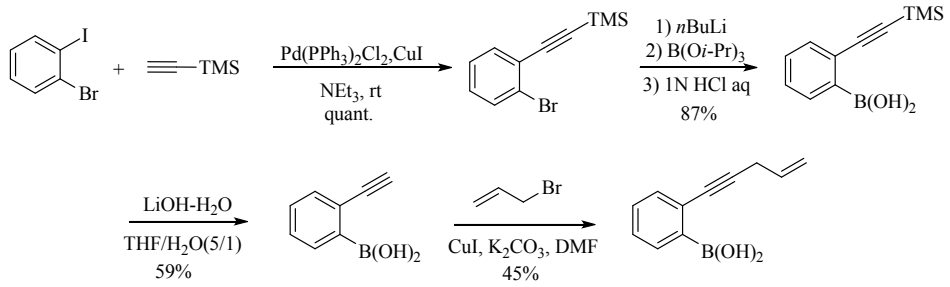
(2-(5-chloropent-1-yn-1-yl)phenyl)boronic acid (1e). Yield: 63% (0.81 g, two steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). White solid. ^{1}H NMR (400 MHz, acetone-d_6) δ 7.85 (d, *J* = 7.3 Hz, 1H), 7.47-7.31 (m, 3H), 7.09 (s, 2H), 3.81 (t, *J* = 6.4 Hz, 2H), 2.70 (t, *J* = 6.9 Hz, 2H), 2.13-2.06 (m,

2H). ^{13}C NMR (101 MHz, acetone-d_6) δ 135.62, 133.21, 130.83, 128.31, 127.84, 92.75, 83.13, 44.55, 32.25, 17.29.

(2-(4-phenylbut-1-yn-1-yl)phenyl)boronic acid (1f). Yield: 72% (1.33 g, two steps). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). White solid. ^{1}H NMR (400 MHz, acetone-d_6) δ 7.88 (d, *J* = 7.3 Hz, 1H), 7.47-7.26 (m, 7H), 7.26-7.14 (m, 1H), 7.05 (s, 2H), 2.95 (t, *J* = 7.3 Hz, 2H), 2.81 (t, *J* = 7.2 Hz, 2H). ^{13}C NMR (101 MHz, acetone-d_6) δ 141.45, 135.85, 133.23, 130.96, 129.39, 129.25, 128.26, 128.08, 127.18, 94.29, 83.02, 35.48, 22.03.

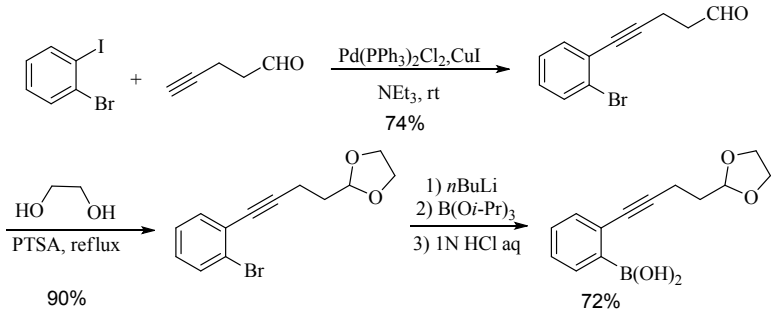
(2-(5-methylhex-1-yn-1-yl)phenyl)boronic acid (1g). Yield: 68% (0.95 g, two steps). R_f = 0.4 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, CD_3OD) δ 7.42-7.17 (m, 4H), 2.42 (t, *J* = 7.2 Hz, 2H), 1.85-1.76 (m, 1H), 1.50-1.45 (m, 2H), 0.95 (d, *J* = 6.6 Hz, 6H). ^{13}C NMR (101 MHz, CD_3OD) δ 132.12, 132.07, 129.58, 128.11, 127.40, 91.79, 82.12, 38.87, 28.16, 22.60, 18.03.

(2-(pent-4-en-1-yn-1-yl)phenyl)boronic acid (1h).



Yield: 23% (120 mg, four steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (dd, *J* = 7.4, 1.1 Hz, 1H), 7.48 (dd, *J* = 7.7, 1.0 Hz, 1H), 7.41 (td, *J* = 7.5, 1.6 Hz, 1H), 7.36 (td, *J* = 7.4, 1.5 Hz, 1H), 5.96-5.86 (m, 1H), 5.63 (br, 2H), 5.41 (ddd, *J* = 17.0, 3.1, 1.7 Hz, 1H), 5.22 (ddd, *J* = 10.0, 2.9, 1.6 Hz, 1H), 3.28 (dt, *J* = 5.4, 1.7 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 135.50, 133.74, 132.69, 131.54, 130.78, 127.92, 117.09, 23.69.

(2-(4-(1,3-dioxolan-2-yl)but-1-yn-1-yl)phenyl)boronic acid (1i).

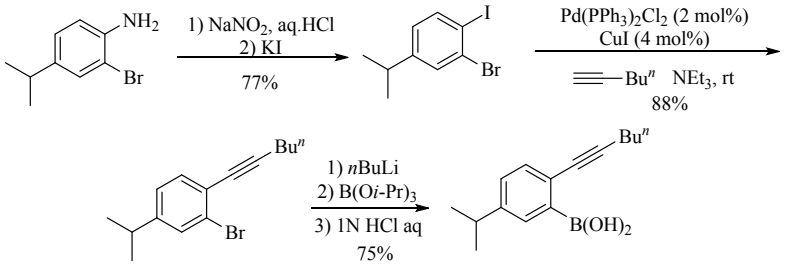


Yield: 48% (1.58 g, three steps). R_f = 0.3 (Petroleum ether: EtOAc = 3:1). Colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (dd, *J* = 7.4, 0.9 Hz, 1H), 7.45 (d, *J* = 7.4 Hz, 1H), 7.39 (td, *J* = 7.5, 1.5 Hz, 1H), 7.34 (td, *J* = 7.3, 1.3 Hz, 1H), 6.01 (brs, 2H), 5.04 (t, *J* = 4.3 Hz, 1H), 4.06-3.99 (m, 2H), 3.93-3.86 (m,

2H), 2.65 (t, J = 7.1 Hz, 2H), 2.03 (td, J = 7.1, 4.4 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 135.47, 132.68, 130.67, 127.68, 127.37, 103.18, 93.82, 81.64, 65.09, 32.31.

(2-(hex-1-yn-1-yl)-5-methylphenyl)boronic acid (1k). Yield: 46% (0.33 g, two steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 7.71 (s, 1H), 7.32 (d, J = 7.8 Hz, 1H), 7.22 (dd, J = 7.8, 1.3 Hz, 1H), 7.12 (brs, 2H), 2.50 (t, J = 7.0 Hz, 2H), 2.33 (s, 3H), 1.64-1.56 (m, 2H), 1.54-1.42 (m, 2H), 0.94 (t, J = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 137.05, 135.71, 132.28, 130.85, 124.37, 93.33, 81.57, 30.61, 21.76, 20.45, 18.52, 12.98.

(2-(hex-1-yn-1-yl)-5-isopropylphenyl)boronic acid (1l).

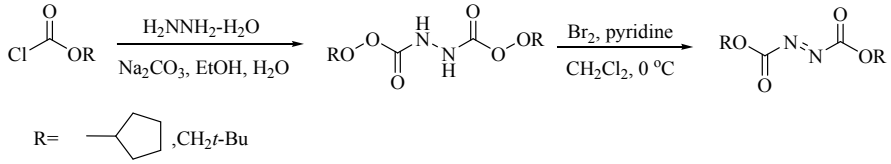


Yield: 51% (1.02 g, three steps). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 7.79 (d, J = 1.7 Hz, 1H), 7.36 (d, J = 7.9 Hz, 1H), 7.29 (dd, J = 8.0, 2.0 Hz, 1H), 7.08 (brs, 2H), 2.92 (dt, J = 13.8, 6.9 Hz, 1H), 2.51 (t, J = 7.0 Hz, 2H), 1.68-1.56 (m, 2H), 1.56-1.44 (m, 2H), 1.23 (d, J = 6.9 Hz, 6H), 0.95 (t, J = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 148.83, 134.03, 133.33, 129.12, 125.72, 94.20, 82.53, 34.75, 31.52, 24.11, 22.64, 19.42, 13.84.

(5-fluoro-2-(hex-1-yn-1-yl)phenyl)boronic acid (1m). Yield: 75% (0.55 g, two steps). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 7.54 (dd, J = 9.5, 2.8 Hz, 1H), 7.48 (dd, J = 8.5, 5.3 Hz, 1H), 7.24 (brs, 2H), 7.17 (td, J = 8.5, 2.9 Hz, 1H), 2.50 (t, J = 7.0 Hz, 2H), 1.65-1.58 (m, 2H), 1.54-1.45 (m, 2H), 0.95 (t, J = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 161.95, 161.47, 135.44 (d, J = 7.6 Hz), 124.44 (d, J = 3.2 Hz), 121.72 (d, J=20.1 Hz), 118.05 (d, J = 22.3 Hz), 94.64, 81.30, 31.40, 22.63, 19.37, 13.83.

Synthesis of azodicarboxylate esters 2a-2g

Compounds **2f**[3] and **2g**[4] were synthesized according to the literature procedure and the analytical data were matched with the reported data. Compounds **2d** and **2e** were synthesized following the known literature procedures via the scheme bellow.[4]



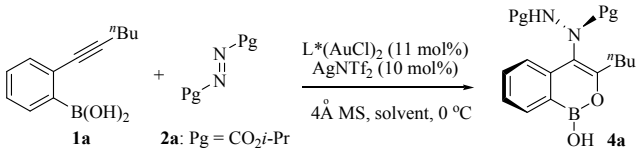
(E)-dicyclopentyl diazene-1,2-dicarboxylate (2d). Yield: 89% (0.70 g, two steps). Yellow oil. ^{1}H

NMR (400 MHz, $CDCl_3$) δ 5.59-5.22 (m, 2H), 2.03-1.62 (m, 16H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.22, 83.29, 32.67, 23.58.

(E)-dineopentyl diazene-1,2-dicarboxylate (2e). Yield: 85% (0.65 g, two steps). Yellow solid. ^1H NMR (400 MHz, $CDCl_3$) δ 4.08 (s, 4H), 0.95 (s, 18H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.61, 77.27, 30.76, 25.13.

Ligands and solvents screen

Table S1 Ligands and solvents effect on the asymmetric gold-catalyzed cycloaddition/amination of **1a** with **2a**[a].



Entry	L*(AuCl)$_2$	Solvent	Yield (%)[b]	Ee (%)[c]
1	**(*R*)-BINAP(AuCl)$_2$**	**DCM**	**83**	**82**
2	(*S*)-(8*H*)-BINAP(AuCl)$_2$	DCM	68	-75
3	(*S*)-Tol-BINAP(AuCl)$_2$	DCM	58	-76
4	(*R*)-DTBM-SEGPHOS (AuCl)$_2$	DCM	31	8
5	(*R*)-BINAP(AuCl)$_2$	Toluene	-	-
6	(*R*)-BINAP(AuCl)$_2$	DCE	61	55
7	(*R*)-BINAP(AuCl)$_2$	THF	-	-

[a] 0.4 mmol **2a**, catalysts and additives were added 1 mL DCM followed by 0.2 mmol **1a** in 1 mL of DCM and the reaction was run for 12 h. [b] Isolated yields after flash chromatography. [c] Determined by HPLC.

Synthesis of 4a-4t

General procedure: A solution of **2** (2 equiv.), (*R*)-BINAP(AuCl)$_2$ (0.11 equiv.), $AgNTf_2$ (0.1 equiv.) and 4Å MS (100 mg) in DCM (1 mL) was stirred at room temperature for 10 min. Then the reaction mixture was cooled to 0 °C, added boronic acid **1** (0.025 M) in DCM (1 mL) and stirred for 24 h (TLC monitored) at that temperature. The resulting mixture was directly purified by flash column chromatography on silica gel to give the product **4** as yellow oil or a white solid and the enantiomeric excesses were determined by HPLC analysis. **4a-4f** and **4t** were obtained from 0.2 mmol of **1** and **4g-4s** were obtained from 0.05 mmol of **1** at the standard conditions. The racemic **4a-4t** were synthesized by using (±)-BINAP(AuCl)$_2$ instead.

Diisopropyl 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4a). Yield: 83% (66.8 mg). R_f = 0.3 (Petroleum ether: EtOAc = 5:1). Colorless oil. **Doubled signals in NMR spectra were observed when 4a was dissolved in deuterium acetone due to the presence of several rotamers. The same situation was to 4b-4t. The spectra got "clean" when 4a was dissolved in deuterium dimethyl sulfoxide at 70 °C (where the barrier of rotation was damaged)**.

^1H NMR (400 MHz, acetone-d_6) δ 8.65 (two singlets, 1H), 8.11 (two singlets, 1H), 8.03 (m, 1H), 7.88-

7.67 (m, 1H), 7.63-7.57 (m, 1H), 7.35 (q, *J* = 7.2 Hz, 1H), 5.02-4.78 (m, 2H), 2.89-2.82 (m, 2H), 1.71-1.63 (m, 2H), 1.46-1.38 (m, 2H), 1.31-0.99 (m, 12H), 0.96-0.91 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.02, 156.90, 156.42, 155.69, 142.28, 133.66, 132.83, 126.40, 126.32, 123.06, 122.88, 121.25, 70.73, 70.61, 69.48, 31.61, 23.38, 22.29, 22.28, 22.25, 22.01, 14.37, 14.34.

^{1}H NMR (400 MHz, DMSO-d_6) δ 9.45 (s, 1H), 9.08 (s, 1H), 8.04 (dd, *J* = 6.8, 0.5 Hz, 1H), 7.73 (s, 1H), 7.65-7.56 (m, 1H), 7.36 (td, *J* = 7.3, 0.7 Hz, 1H), 4.99-4.74 (m, 2H), 2.84-2.76 (m, 1H), 2.68-2.62 (m, 1H), 1.74-1.58 (m, 2H), 1.45-1.36 (m, 2H), 1.35-0.99 (m, 12H), 0.96 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 155.75, 155.39, 154.94, 140.70, 132.55, 131.51, 125.13, 123.04, 121.92, 119.69, 69.41, 68.18, 30.27, 28.30, 21.88, 21.65, 21.61, 21.44 (brs, 2C), 13.50.

IR (neat) γ 3401, 3274, 2958, 1710, 1397, 1303, 1244, 1058 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{20}H_{30}BN_2O_6$ $[M + H]^+$ 405.21969, found 405.21872. $[\alpha]_D^{20}$ = +14° (*c* 0.97, $CHCl_3$). Enantiomeric excess: 82%, determined by chiral HPLC analysis [Daicel Chiralpak AS, *n*-Hexane: 2-propanol = 97:3, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 11.64 min; t_R (*R*) = 20.27 min].

Diethyl 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4b). Yield: 92% (69.2 mg). R_f = 0.3 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.83 (two singlets, 1H), 8.17 (two singlets, 1H), 8.08 (d, *J* = 7.3 Hz, 1H), 7.78 (d, *J* = 7.4 Hz, 1H), 7.67-7.60 (m, 1H), 7.42-7.36 (m, 1H), 4.44-3.99 (m, 4H), 2.95-2.80 (m, 2H), 1.77-1.60 (m, 2H), 1.48-1.43 (m, 2H), 1.34-1.10 (m, 6H), 0.97 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.35, 157.07, 156.96, 156.84, 156.14, 142.19, 133.72, 132.95, 132.83, 126.47, 126.36, 122.90, 122.82, 121.14, 63.06, 61.94, 31.70, 31.59, 23.34, 14.91, 14.84, 14.34. IR (neat) γ 3412, 3285, 2958, 1710, 1397, 1302, 1244, 1070 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{18}H_{26}BN_2O_6$ $[M + H]^+$ 377.18839, found 377.18768. $[\alpha]_D^{20}$ = +16° (*c* 1.09, $CHCl_3$). Enantiomeric excess: 62%, determined by chiral HPLC analysis [Daicel Chiralpak AS, *n*-Hexane: 2-propanol = 90:10, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 4.50 min; t_R (*R*) = 7.25 min].

Dibenzyl 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4c). Yield: 60% (60.0 mg). R_f = 0.3 (Petroleum ether: EtOAc = 3:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 9.34-8.88 (m, 1H), 8.20 (s, 1H), 8.08 (d, *J* = 7.4 Hz, 1H), 7.84-7.73 (m, 1H), 7.61 (s, 1H), 7.55-7.00 (m, 11H), 5.34-5.06 (m, 4H), 3.04-2.87 (m, 1H), 2.81-2.78 (m, 1H), 1.69-1.60 (m, 2H), 1.43-1.33 (m, 2H), 0.96-0.88 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.82, 157.28, 157.17, 156.90, 156.07, 142.06, 137.47, 137.33, 133.77, 133.00, 132.89, 129.28, 129.13, 128.90, 128.88, 128.84, 128.65, 128.41, 126.53, 126.44, 122.83, 121.06, 68.60, 67.62, 31.77, 31.63, 31.15, 31.08, 23.29, 14.34. IR (neat) γ 3412, 3289, 2956, 1709, 1389, 1298, 1253, 1054, 690 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{28}H_{30}BN_2O_6$ $[M + H]^+$ 501.21969, found 501.21875. $[\alpha]_D^{20}$ = -9° (*c* 1.89, $CHCl_3$). Enantiomeric

excess: 59%, determined by chiral HPLC analysis [Daicel Chiralpak AS, *n*-Hexane:2-propanol = 90:10, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 12.08 min; t_R (*R*) = 19.44 min].

Dicyclopentyl 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4d). Yield: 61% (55.8 mg). R_f = 0.5 (Petroleum ether: EtOAc = 4:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.68 (two singlets, 1H), 8.11 (two singlets, 1H), 8.04 (d, *J* = 7.0 Hz, 1H), 7.86-7.66 (m, 1H), 7.63-7.56 (m, 1H), 7.37-7.32 (m, 1H), 5.16-5.08 (m, 2H), 2.93-2.88 (m, 1H), 2.83-2.77 (m, 1H), 1.97-1.52 (m, 16H), 1.44-1.29 (m, 4H), 0.94 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.60, 157.24, 157.17, 156.92, 156.59, 155.83, 142.32, 133.68, 132.81, 126.39, 122.74, 121.39, 80.01, 78.89, 33.57, 33.34, 33.30, 33.11, 31.52, 24.22, 23.98, 23.77, 23.32, 14.40. IR (neat) γ 3412, 3289, 2956, 1709, 1389, 1298, 1253, 1054, 690 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{24}H_{34}BN_2O_6$ $[M + H]^+$ 457.25099, found 457.25024. $[\alpha]_D^{20}$ = -16° (*c* 1.08, $CHCl_3$). Enantiomeric excess: 77%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-propanol = 95:5, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 7.77 min; t_R (*R*) = 10.87 min].

Dineopentyl 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4e). Yield: 79% (72.9 mg). R_f = 0.6 (Petroleum ether: EtOAc = 4:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.93 (two singlets, 1H), 8.12 (two singlets, 1H), 8.05 (d, *J* = 6.8 Hz, 1H), 7.75 (d, *J* = 7.9 Hz, 1H), 7.62-7.55 (m, 1H), 7.37-7.32 (m, 1H), 3.97-3.64 (m, 4H), 2.84-2.76 (m, 2H), 1.74-1.54 (m, 2H), 1.45-1.40 (m, 2H), 1.03-0.61 (m, 21H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.74, 155.98, 155.31, 141.40, 141.24, 132.85, 131.98, 125.55, 121.94, 120.52, 75.35, 74.10, 31.46, 31.35, 31.13, 30.99, 30.79, 30.64, 25.69, 25.43, 22.44, 22.40, 13.48, 13.45. IR (neat) γ 3396, 3290, 2956, 2864, 1693, 1389, 1298, 1237, 1070, 765 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{24}H_{38}BN_2O_6$ $[M + H]^+$ 461.28229, found 461.28079. $[\alpha]_D^{20}$ = +16° (*c* 1.08, $CHCl_3$). Enantiomeric excess: 81%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-propanol = 95:5, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 4.36 min; t_R (*R*) = 6.50 min].

Bis(2,2,2-trichloroethyl) 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4f). Yield: 82% (95.3 mg). R_f = 0.6 (Petroleum ether: EtOAc = 4:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 9.79 (two singlets, 1H), 8.21 (two singlets, 1H), 8.05 (d, *J* = 7.3 Hz, 1H), 7.81-7.73 (m, 1H), 7.63-7.59 (t, *J* = 7.6 Hz, 1H), 7.37 (t, *J* = 7.2 Hz, 1H), 5.01-4.77 (m, 4H), 3.00-2.92 (m, 1H), 2.86-2.75 (m, 1H), 1.80-1.55 (m, 2H), 1.43-1.39 (m, 2H), 0.95-0.90 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 158.27, 157.87, 155.53, 155.27, 155.22, 154.51, 141.58, 141.33, 133.82, 133.05, 126.71, 122.69, 120.39, 109.70, 96.34, 96.29, 96.26, 95.99, 76.90, 76.29, 75.46, 31.83, 31.75, 23.36, 14.39. IR (neat) γ 3304, 2956, 1739, 1404, 1222, 1115,720 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{18}H_{20}BCl_6N_2O_6$ $[M + H]^+$ 580.95456, found 580.95401. $[\alpha]_D^{20}$ = +17° (*c* 1.82, $CHCl_3$). Enantiomeric

excess: 80%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-propanol = 90:10, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 6.96 min; t_R (*R*) = 8.81 min].

Di-tert-butyl 1-(3-butyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4g). Yield: 70% (15.1 mg). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.39 (two singlets, 1H), 8.05 (two singlets, 1H), 8.02-8.01 (m, 1H), 7.81-7.70 (m, 1H), 7.63-7.56 (m, 1H), 7.37-7.31 (m, 1H), 2.87-2.79 (m, 2H), 1.72-1.61 (m, 2H), 1.53-1.27 (m, 20H), 1.01-0.90 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.43, 156.60, 156.45, 156.29, 155.68, 142.48, 133.64, 132.75, 126.27, 123.05, 122.88, 121.76, 121.24, 81.42, 80.61, 31.72, 31.57, 28.54, 28.51, 28.40, 28.26, 23.36, 14.44. IR (neat) γ 3396, 2986, 1709, 1374, 1161 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{22}H_{34}BN_2O_6$ $[M + H]^+$ 433.25099, found 433.24982. ^{13}C NMR (101 MHz, Acetone-d_6) δ 156.45, 156.29, 155.68, 142.48, 133.64, 132.75, 126.27, 122.88, 81.42, 80.61, 31.72, 31.57, 28.54, 28.51, 28.40, 28.26, 23.36, 14.44. $[\alpha]_D^{20}$ = +24° (*c* 0.19, $CHCl_3$). Enantiomeric excess: 89%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-propanol = 95:5, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 4.16 min; t_R (*S*) = 4.46 min].

Di-tert-butyl 1-(1-hydroxy-3-propyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-di-carboxylate (4h). Yield: 88% (18.4 mg). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.39 (two singlets, 1H), 8.07 (two singlets, 1H), 8.04-7.98 (m, 1H), 7.82-7.71 (m, 1H), 7.64-7.56 (m, 1H), 7.37-7.32 (m, 1H), 2.81-2.67 (m, 2H), 1.75-1.68 (m, 2H), 1.53-1.29 (m, 20H), 1.01-0.95 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.50, 156.32, 155.64, 142.20, 133.62, 132.75, 126.30, 123.10, 122.93, 81.29, 80.50, 33.49, 28.48, 28.36, 28.22, 20.85, 14.22. IR (neat) γ 3365, 2986, 1709, 1374, 1161, 765 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{21}H_{32}BN_2O_6$ $[M + H]^+$ 419.23534, found 419.23418. $[\alpha]_D^{20}$ = +12° (*c* 0.34, $CHCl_3$). Enantiomeric excess: 84%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-propanol = 97:3, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 11.47 min; t_R (*S*) = 12.83 min].

Di-tert-butyl 1-(1-hydroxy-3-pentyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4i). Yield: 78% (17.4 mg). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.39 (two singlets, 1H), 8.07 (two singlets, 1H), 8.08-8.01 (m, 1H), 7.86-7.66 (m, 1H), 7.67-7.48 (m, 1H), 7.37-7.31 (m, 1H), 2.89-2.69 (m, 2H), 1.72-1.69 (m, 2H), 1.59-1.07 (m, 22H), 0.91 (t, *J* = 6.5 Hz, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.43, 156.46, 156.30, 155.67, 142.47, 133.65, 132.76, 126.28, 123.06, 122.89, 121.73, 121.25, 81.41, 80.55, 32.71, 31.93, 31.79, 28.56, 28.52, 28.41, 28.27, 27.39, 23.43, 14.42. IR (neat) γ 3365, 2986, 1709, 1374, 1161, 765 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{23}H_{36}BN_2O_6$ $[M + H]^+$ 447.26664, found 447.26526. $[\alpha]_D^{20}$ = +13° (*c* 0.32, $CHCl_3$). Enantiomeric excess: 89%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-

propanol = 98:2, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 5.27 min; t_R (*S*) = 6.13 min].

Di-tert-butyl 1-(3-hexyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4j). Yield: 81% (18.7 mg). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.38 (two singlets, 1H), 8.07 (two singlets, 1H), 8.08-8.01 (m, 1H), 7.81-7.70 (m, 1H), 7.66-7.51 (m, 1H), 7.39-7.28 (m, 1H), 2.85-2.79 (m, 2H), 1.71-1.66 (m, 2H), 1.53-1.30 (m, 24H), 0.94-0.77 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.44, 156.62, 156.46, 156.30, 155.67, 155.10, 142.48, 133.65, 132.75, 126.28, 123.06, 122.88, 121.71, 121.24, 81.33, 80.52, 32.71, 32.61, 31.86, 28.56, 28.52, 28.41, 28.27, 27.68, 23.29, 14.41. IR (neat) γ 3396, 2940, 1693, 1374, 1161, 765 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{24}H_{38}BN_2O_6$ $[M + H]^+$ 461.28229, found 461.28098. $[\alpha]_D^{20}$ = +16° (*c* 0.37, $CHCl_3$). Enantiomeric excess: 89%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane:2-propanol = 98:2, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 5.21 min; t_R (*S*) = 6.00 min].

Di-tert-butyl 1-(3-(3-chloropropyl)-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4k). Yield: 78% (17.7 mg). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.46 (two singlets, 1H), 8.17 (two singlets, 1H), 8.06-8.03 (m, 1H), 7.78-7.68 (m, 1H), 7.66-7.53 (m, 1H), 7.40-7.33 (m, 1H), 3.81-3.64 (m, 2H), 2.31-2.08 (m, 2H), 1.61-1.15 (m, 20H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.60, 155.55, 155.11, 142.16, 133.76, 132.88, 126.58, 126.52, 123.05, 122.87, 81.69, 45.40, 31.23, 29.40, 28.52, 28.42, 28.27, 15.65. IR (neat) γ 3335, 2986, 1709, 1374, 1253, 1161, 751 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{21}H_{31}BClN_2O_6$ $[M + H]^+$ 453.19637, found 453.19495. $[\alpha]_D^{20}$ = +18° (*c* 0.18, $CHCl_3$). Enantiomeric excess: 87%, determined by chiral HPLC analysis [Daicel Chiralpak AD, *n*-Hexane: 2-propanol = 98:2, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 12.29 min; t_R (*R*) = 17.31 min].

Di-tert-butyl 1-(1-hydroxy-3-phenethyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4l). Yield: 65% (15.6 mg). R_f = 0.4 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.37 (two singlets, 1H), 8.18 (two singlets, 1H), 8.10-8.00 (m, 1H), 7.83-7.70 (m, 1H), 7.63-7.58 (m, 1H), 7.46-7.23 (m, 5H), 7.22-7.13 (m, 1H), 3.35-2.88 (m, 4H), 1.52-1.31 (m, 18H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.50, 155.60, 155.16, 143.05, 142.88, 142.32, 133.74, 132.88, 129.36, 129.21, 129.16, 126.76, 126.50, 123.06, 122.88, 81.45, 34.38, 33.81, 28.51, 28.42, 28.28. IR (neat) γ 3365, 2970, 1709, 1253, 1100, 1024, 796 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{26}H_{34}BN_2O_6$ $[M + H]^+$ 481.25099, found 481.24985. $[\alpha]_D^{20}$ = -10° (*c* 0.31, $CHCl_3$). Enantiomeric excess: 88%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane: 2-propanol = 97:3, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 5.06 min; t_R (*S*) = 5.88 min].

Di-tert-butyl 1-(1-hydroxy-3-isopentyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-

dicarboxylate (4m). Yield: 66% (14.7 mg). R_f = 0.4 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.40 (m, 1H), 8.08 (m, 1H), 8.05-7.99 (m, 1H), 7.83-7.66 (m, 1H), 7.65-7.51 (m, 1H), 7.40-7.29 (m, 1H), 3.02-2.84 (m, 1H), 1.73-1.66 (m, 1H), 1.62-1.59 (m, 1H), 1.54-1.29 (m, 20H), 0.98-0.93 (m, 6H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.43, 156.28, 155.67, 142.49, 133.64, 132.76, 126.27, 126.20, 123.04, 122.86, 81.34, 80.53, 36.70, 36.64, 28.98, 28.51, 28.42, 28.28, 23.06, 22.91. IR (neat) γ 3365, 2970, 1709, 1253, 1100, 1024, 796 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{23}H_{36}BN_2O_6$ $[M + H]^+$ 447.26664, found 447.26511. $[\alpha]_D^{20}$ = +22° (*c* 0.30, $CHCl_3$). Enantiomeric excess: 86%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane: 2-propanol = 98:2, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 4.82 min; t_R (*S*) = 5.36 min].

Di-tert-butyl 1-(3-allyl-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4n). Yield: 48% (10.0 mg). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.47 (two singlets, 1H), 8.21 (two singlets, 1H), 8.06-8.02 (m, 1H), 7.85-7.52 (m, 2H), 7.43-7.29 (m, 1H), 6.10-5.89 (m, 1H), 5.32-5.16 (m, 1H), 5.11-5.04 (m, 1H), 3.80-3.47 (m, 2H), 1.52-1.31 (m, 18H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.56, 155.58, 154.23, 142.37, 135.10, 133.75, 132.86, 126.56, 122.83, 117.29, 81.50, 80.70, 36.41, 28.52, 28.48, 28.38, 28.22. IR (neat) γ 3389, 2984, 1706, 1375, 1149 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{21}H_{30}BN_2O_6$ $[M + H]^+$ 417.21969, found 417.21881. $[\alpha]_D^{20}$ = +31° (*c* 0.10, $CHCl_3$). Enantiomeric excess: 91%, determined by chiral HPLC analysis [Daicel Chiralpak AD, *n*-Hexane: 2-propanol = 97:3, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 18.58 min; t_R (*R*) = 21.85 min].

Di-tert-butyl 1-(3-(2-(1,3-dioxolan-2-yl)ethyl)-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl) hydrazine-1,2-dicarboxylate (4o). Yield: 62% (14.8 mg). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.31 (two singlets, 1H), 8.10 (two singlets, 1H), 7.92-7.85 (m, 1H), 7.85-7.66 (m, 1H), 7.55-7.39 (m, 1H), 7.25-7.19 (m, 1H), 4.84-4.70 (m, 1H), 3.84-3.80 (m, 2H), 3.77-3.66 (m, 2H), 2.81-2.56 (m, 2H), 1.87-1.76 (m, 2H), 1.41-1.16 (m, 18H). ^{13}C NMR (101 MHz, acetone-d_6) δ 155.37, 155.21, 154.64, 141.37, 132.75, 131.95, 125.62, 122.24, 103.48, 80.59, 79.68, 64.66, 64.56, 27.60, 27.51, 27.35, 25.97. IR (neat) γ 3374, 2968, 1720, 1375, 1254, 1164, 774 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{23}H_{34}BN_2O_8$ $[M + H]^+$ 477.24082, found 477.24082. $[\alpha]_D^{20}$ = -17° (*c* 0.08, $CHCl_3$). Enantiomeric excess: 90%, determined by chiral HPLC analysis [Daicel Chiralpak AD, *n*-Hexane: 2-propanol = 90:10, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) =18.93 min; t_R (*S*) = 21.34 min].

Di-tert-butyl 1-(1-hydroxy-3-phenyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4p). Yield: 35% (7.9 mg). R_f = 0.4 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.34 (s, 1H), 8.27 (m, 1H), 8.13-8.04 (m, 1H), 7.75-7.58 (m, 3H), 7.52-

7.21 (m, 5H), 1.50-1.27 (m, 18H). ^{13}C NMR (101 MHz, acetone-d_6) δ 155.87, 155.37, 154.96, 142.51, 136.33, 133.33, 132.58, 129.90, 129.54, 128.78, 128.57, 127.17, 125.17, 123.38, 82.17, 80.22, 28.48, 28.42, 28.38, 28.35. IR (neat) γ 2922, 2848, 1720, 1359, 1149 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{24}H_{30}BN_2O_6$ $[M + H]^+$ 453.21969, found 453.21866. $[\alpha]_D^{20}$ = +16° (*c* 0.09, $CHCl_3$). Enantiomeric excess: 77%, determined by chiral HPLC analysis [Daicel Chiralpak AD, *n*-Hexane: 2-propanol = 97:3, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm., t_R (*S*) = 5.94 min; t_R (*R*) = 11.14 min].

Di-tert-butyl 1-(3-butyl-1-hydroxy-7-methyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4q). Yield: 73% (16.3 mg). R_f = 0.4 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.36 (two singlets, 1H), 7.96 (two singlets, 1H), 7.83-7.82 (m, 1H), 7.71-7.59 (m, 1H), 7.45-7. 39 (m, 1H), 2.92-2.74 (m, 2H), 2.39 (d, *J* = 6.3 Hz, 3H), 1.69-1.63 (m, 2H), 1.51-1.31 (m, 20H), 0.97-0.91 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.38, 155.65, 155.01, 140.04, 135.67, 133.80, 130.53, 122.95, 81.31, 80.51, 32.62, 31.46, 28.52, 28.48, 28.37, 28.24, 23.35, 21.22, 14.42. IR (neat) γ 3335, 2970, 1709, 1496, 1374, 1161 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{23}H_{36}BN_2O_6$ $[M + H]^+$ 447.26664, found 447.26526. $[\alpha]_D^{20}$ = +19° (*c* 0.33, $CHCl_3$). Enantiomeric excess: 88%, determined by chiral HPLC analysis [Daicel Chiralpak AD, *n*-Hexane: 2-propanol = 98:2, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 10.89 min; t_R (*R*) = 14.85 min].

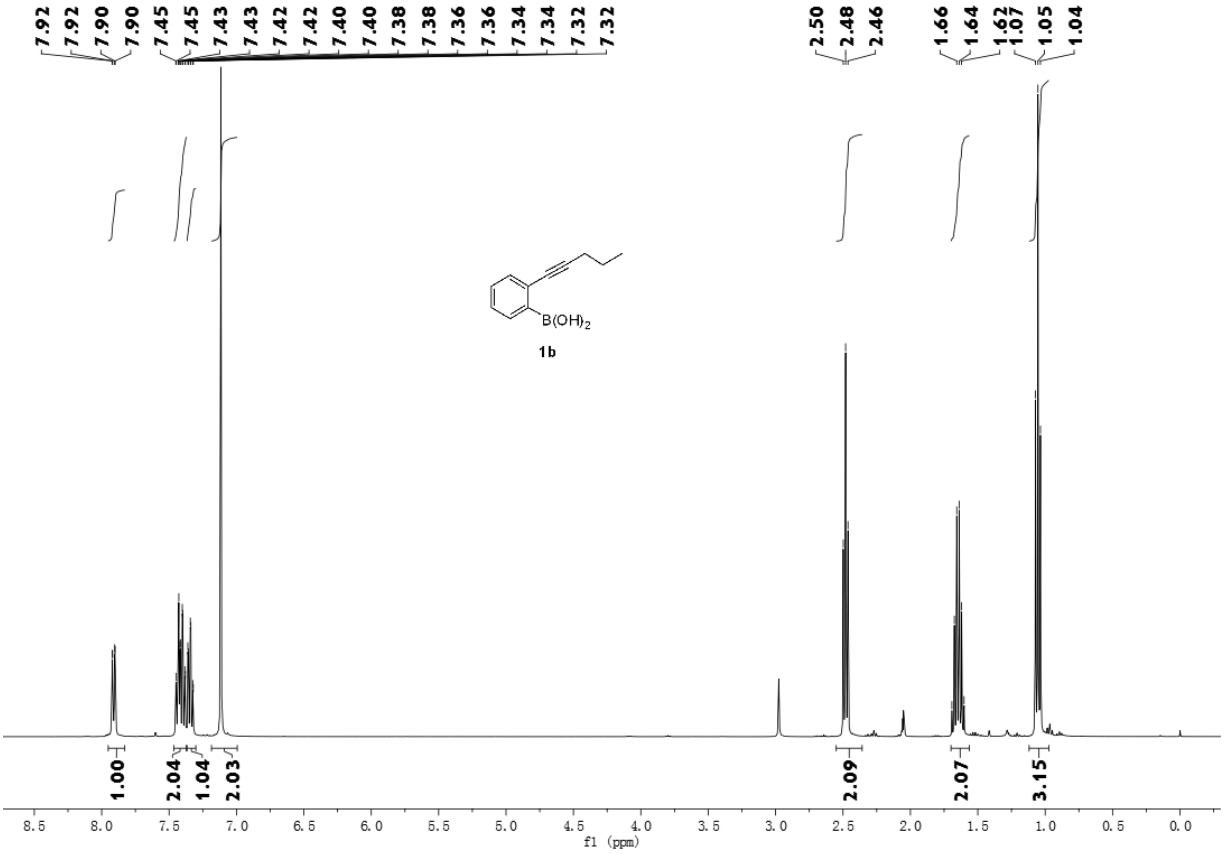
Di-tert-butyl 1-(3-butyl-1-hydroxy-7-isopropyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4r). Yield: 72% (17.1 mg). R_f = 0.6 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.35 (two singlets, 1H), 8.01 (two singlets, 1H), 7.92-7.91 (m, 1H), 7.74-7.62 (m, 1H), 7.53-7.47 (m, 1H), 3.03-2.94 (m, 1H), 2.88-2.74 (m, 2H), 1.70-1.65 (m, 2H), 1.54-1.31 (m, 20H), 1.29-1.26 (m, 6H), 0.97-0.91 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 156.41, 155.70, 155.09, 146.68, 140.45, 131.39, 131.00, 123.25, 123.02, 121.70, 81.27, 80.46, 34.66, 31.49, 28.53, 28.49, 28.39, 28.27, 24.41, 24.32, 23.36, 14.43. IR (neat) γ 3381, 2970, 1709, 1496, 1374, 1161 cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{25}H_{40}BN_2O_6$ $[M + H]^+$ 475.29794, found 475.29684. $[\alpha]_D^{20}$ = +22° (*c* 0.34, $CHCl_3$). Enantiomeric excess: 88%, determined by chiral HPLC analysis [Daicel Chiralpak AD, *n*-Hexane: 2-propanol = 97:3, flow rate 0.5 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 19.56 min; t_R (*S*) = 24.40 min].

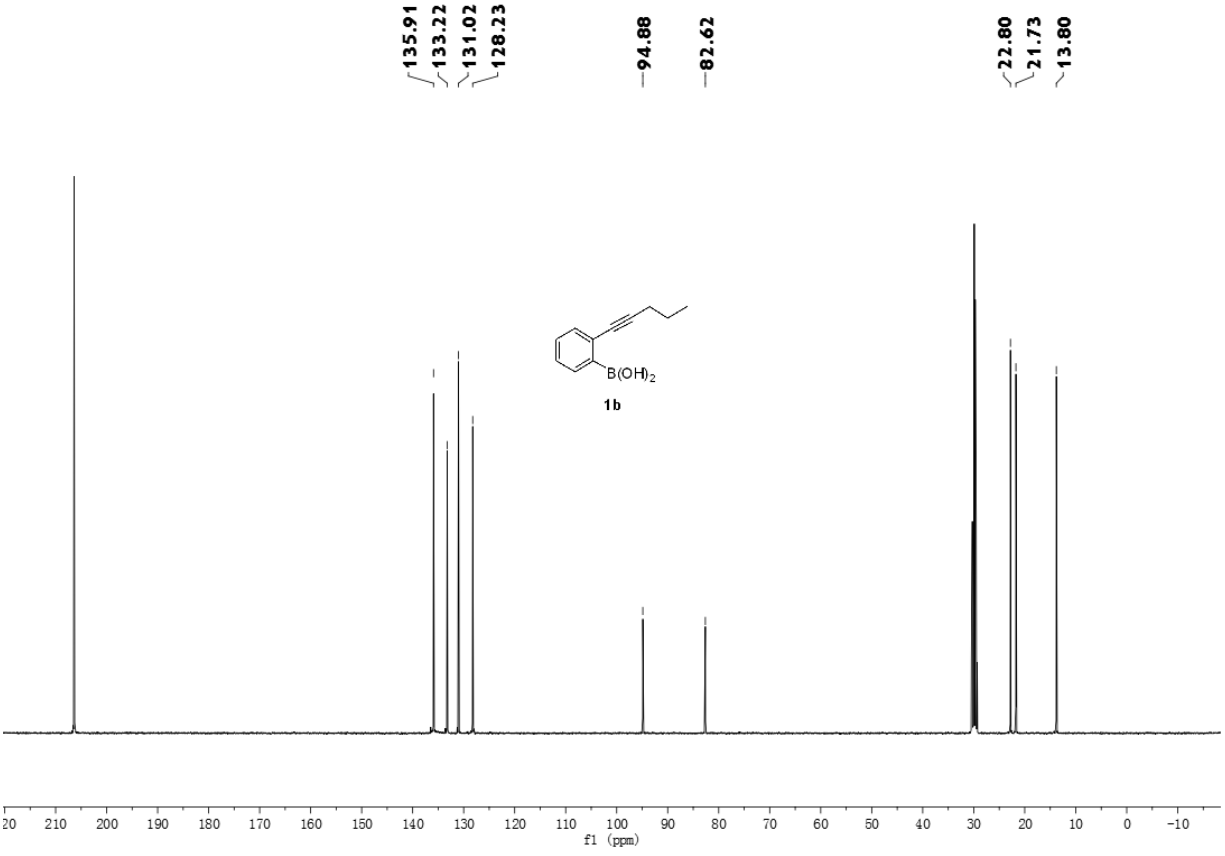
Di-tert-butyl 1-(3-butyl-7-fluoro-1-hydroxy-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4s). Yield: 81% (18.3 mg). R_f = 0.5 (Petroleum ether: EtOAc = 5:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.45 (two singlets, 1H), 8.24 (two singlets, 1H), 7.90 (d, 1H), 7.75-7.59 (m, 1H), 7.42-7.32 (m, 1H), 2.80-2.66 (m, 2H), 1.71-1.61 (m, 2H), 1.53-1.30 (m, 20H), 0.97-0.91 (m, 3H). ^{13}C NMR (101 MHz, acetone-d_6) δ 162.95, 160.51, 156.57, 155.41, 155.01, 139.07, 130.56, 126.11, 125.92, 121.26, 120.13, 118.25, 81.48, 80.68, 31.56, 31.42, 28.50, 28.47, 28.35, 28.21, 23.31,

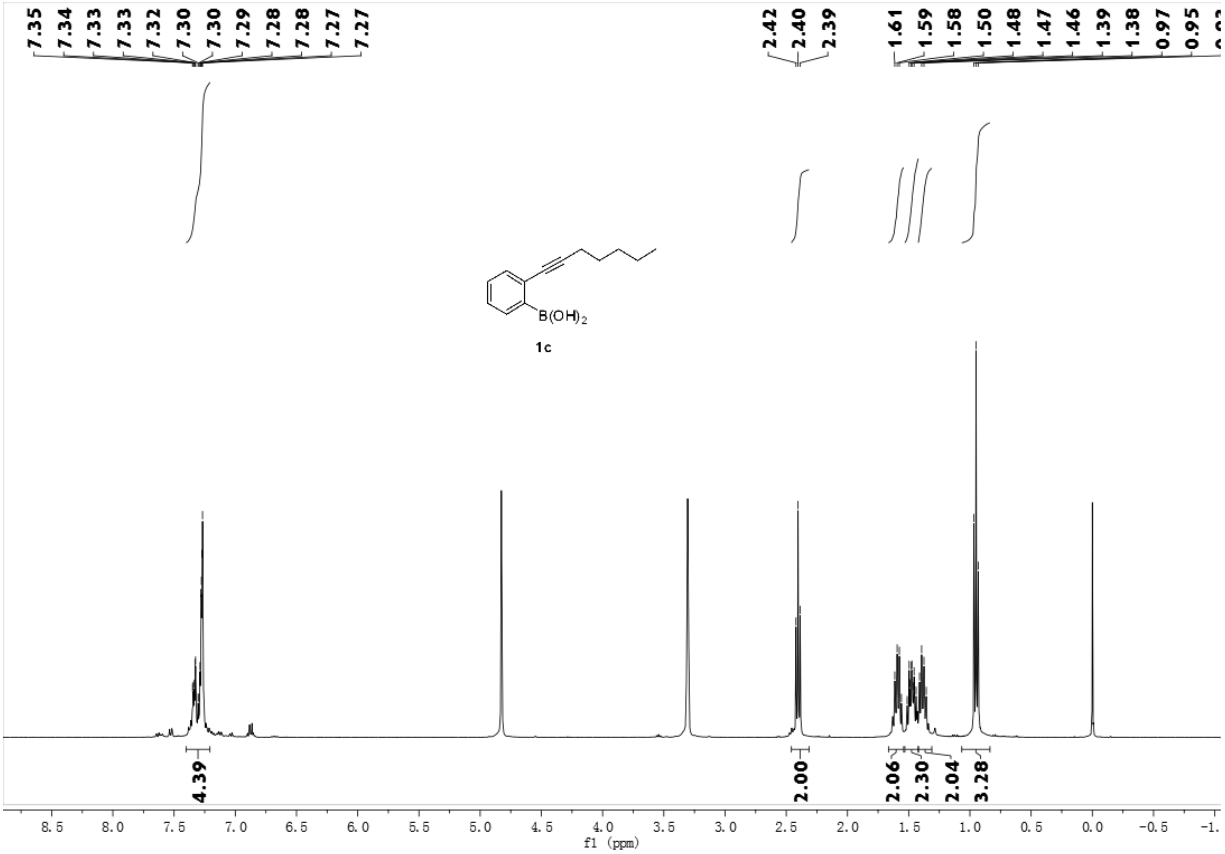
14.33. IR (neat) γ 3396, 2940, 1709, 1496, 1374, 1161cm^{-1}. HRMS (ESI): *m/z* Calcd for $C_{22}H_{33}BFN_2O_6$ $[M + H]^+$ 451.24157, found 451.24014. $[\alpha]_D^{20}$ = +13° (*c* 0.29, $CHCl_3$). Enantiomeric excess: 74%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane: 2-propanol = 97:3, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*R*) = 4.52 min; t_R (*S*) = 5.56 min].

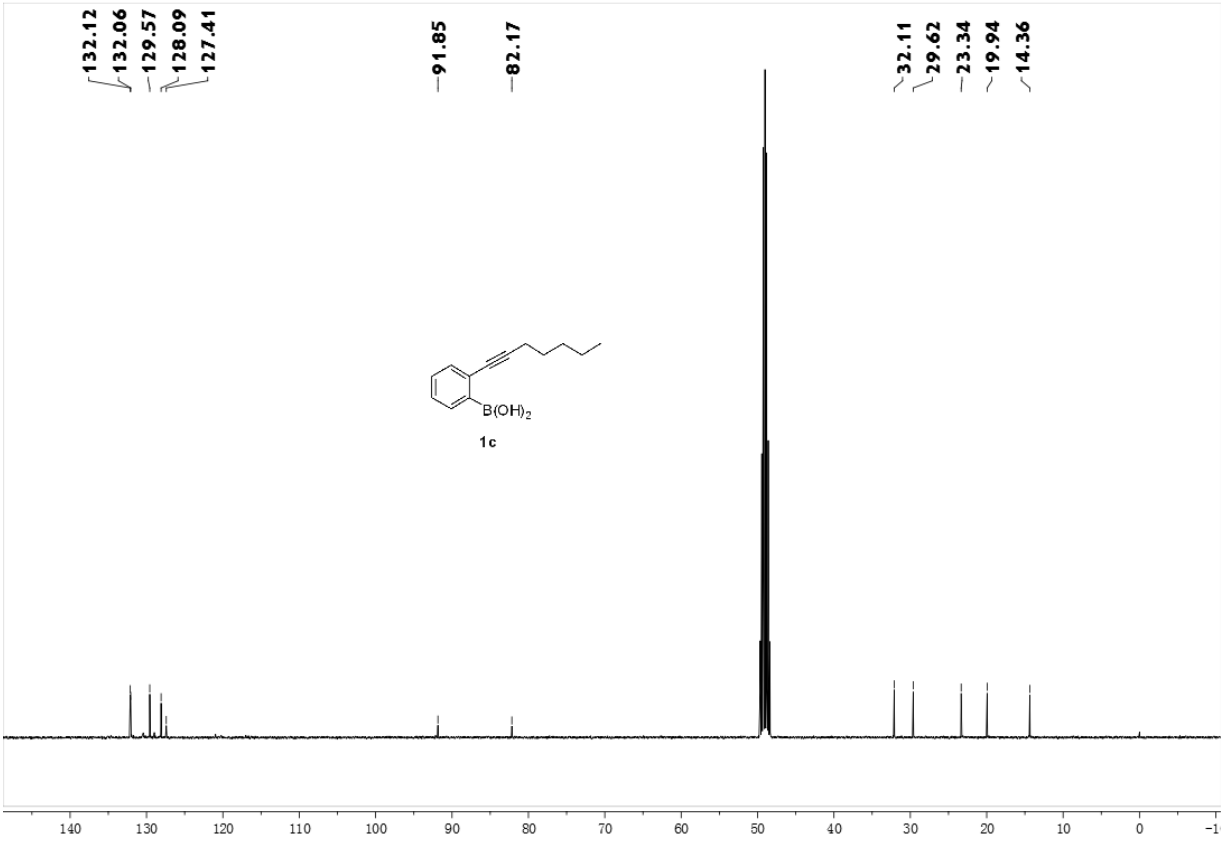
Diisopropyl 1-(1-hydroxy-3-propyl-1H-benzo[c][1,2]oxaborinin-4-yl)hydrazine-1,2-dicarboxylate (4t). Yield: 89% (69.1 mg). R_f = 0.5 (Petroleum ether: EtOAc = 3:1). Colorless oil. ^{1}H NMR (400 MHz, acetone-d_6) δ 8.65 (two singlets, 1H), 8.11 (two singlets, 1H), 8.05-8.02 (m, 1H), 7.89-7.67 (m, 1H), 7.64-7.57 (m, 1H), 7.38-7.33 (m, 1H), 5.02-4.76 (m, 2H), 2.85-2.63 (m, 2H), 1.75-1.69 (m, 2H), 1.33-0.97 (m, 15H). ^{13}C NMR (101 MHz, acetone-d_6) δ 157.86, 156.41, 142.26, 133.66, 132.84, 126.35, 122.90, 121.39, 70.73, 69.51, 33.60, 22.29, 22.26, 22.15, 22.02, 20.82, 14.27. HRMS (ESI): *m/z* Calcd for $C_{19}H_{28}BN_2O_6$ $[M + H]^+$ 391.20404, found 391.20377. $[\alpha]_D^{20}$ = +9° (*c* 1.4, $CHCl_3$). Enantiomeric excess: 80%, determined by chiral HPLC analysis [Daicel Chiralpak IC, *n*-Hexane: 2-propanol = 97:3, flow rate 1.0 ml/min, T = 30 °C, λ = 254 nm. t_R (*S*) = 5.68 min; t_R (*R*) = 8.89 min].

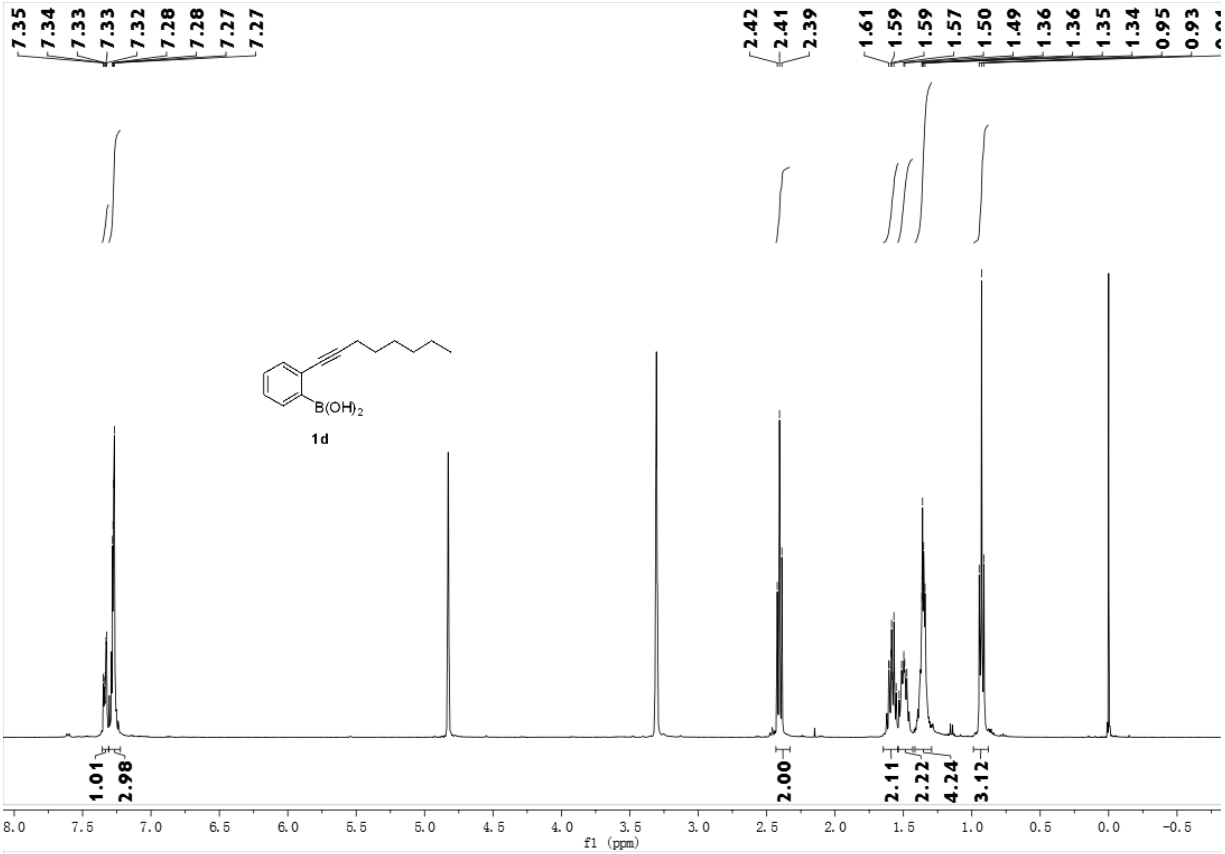
Part II Copies of NMR Spectra of compounds

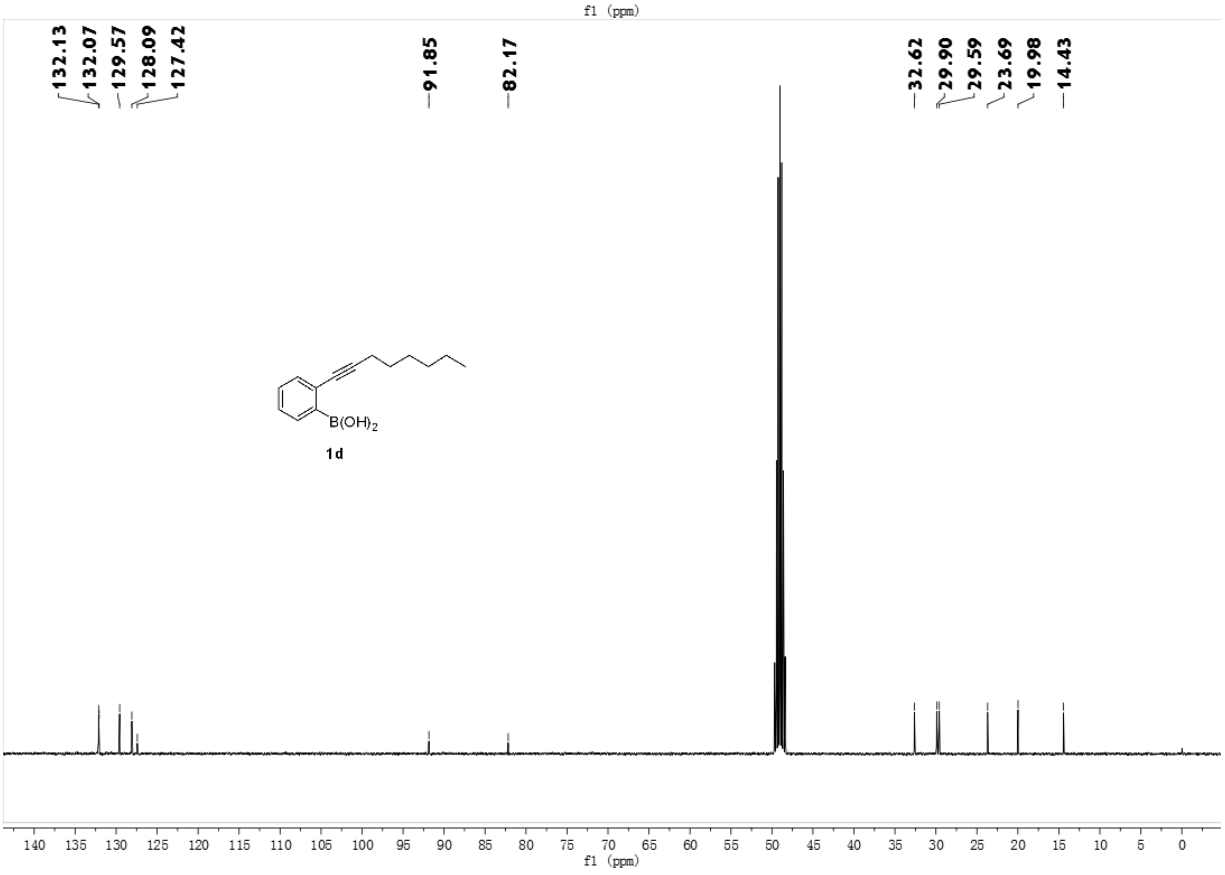


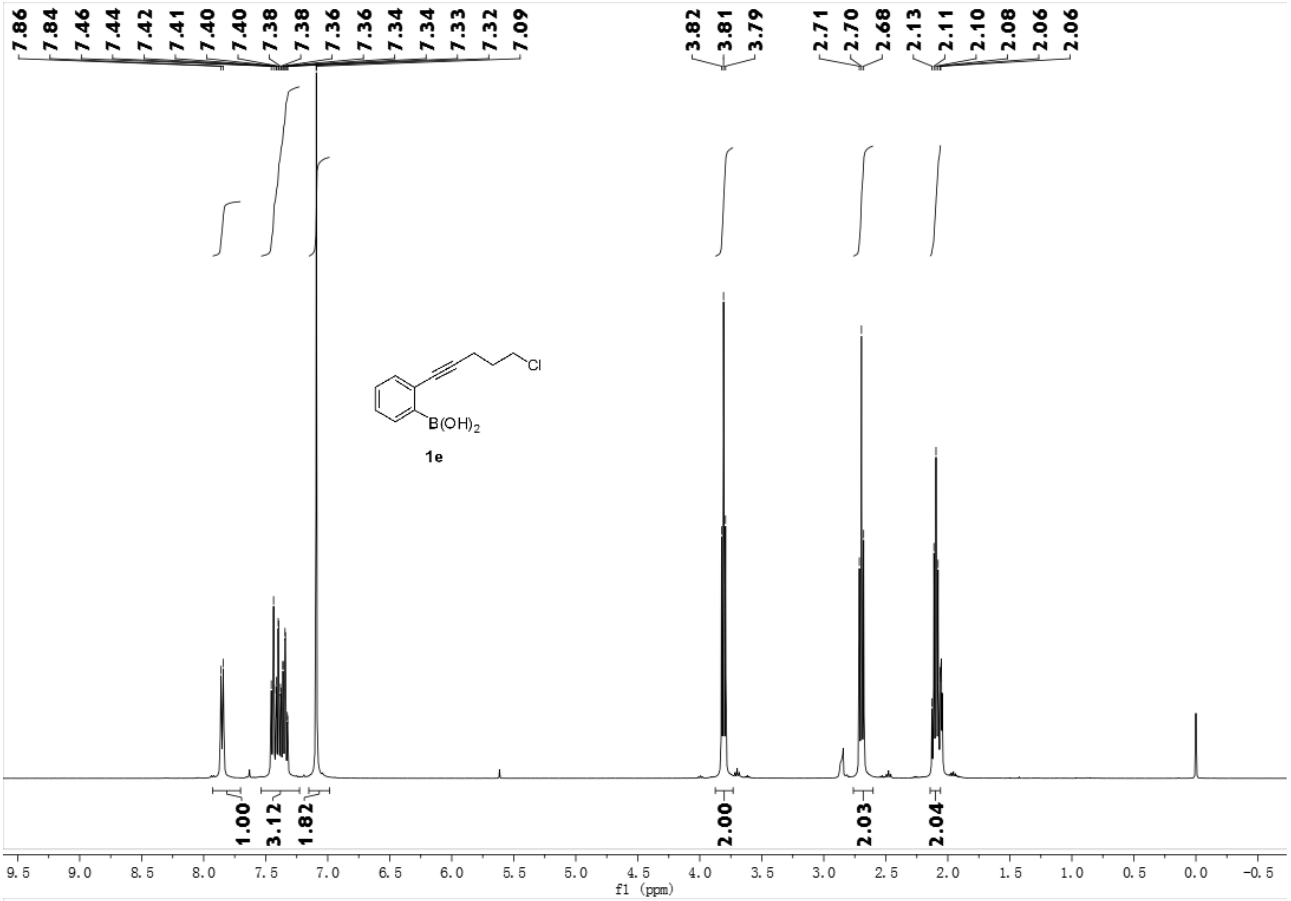


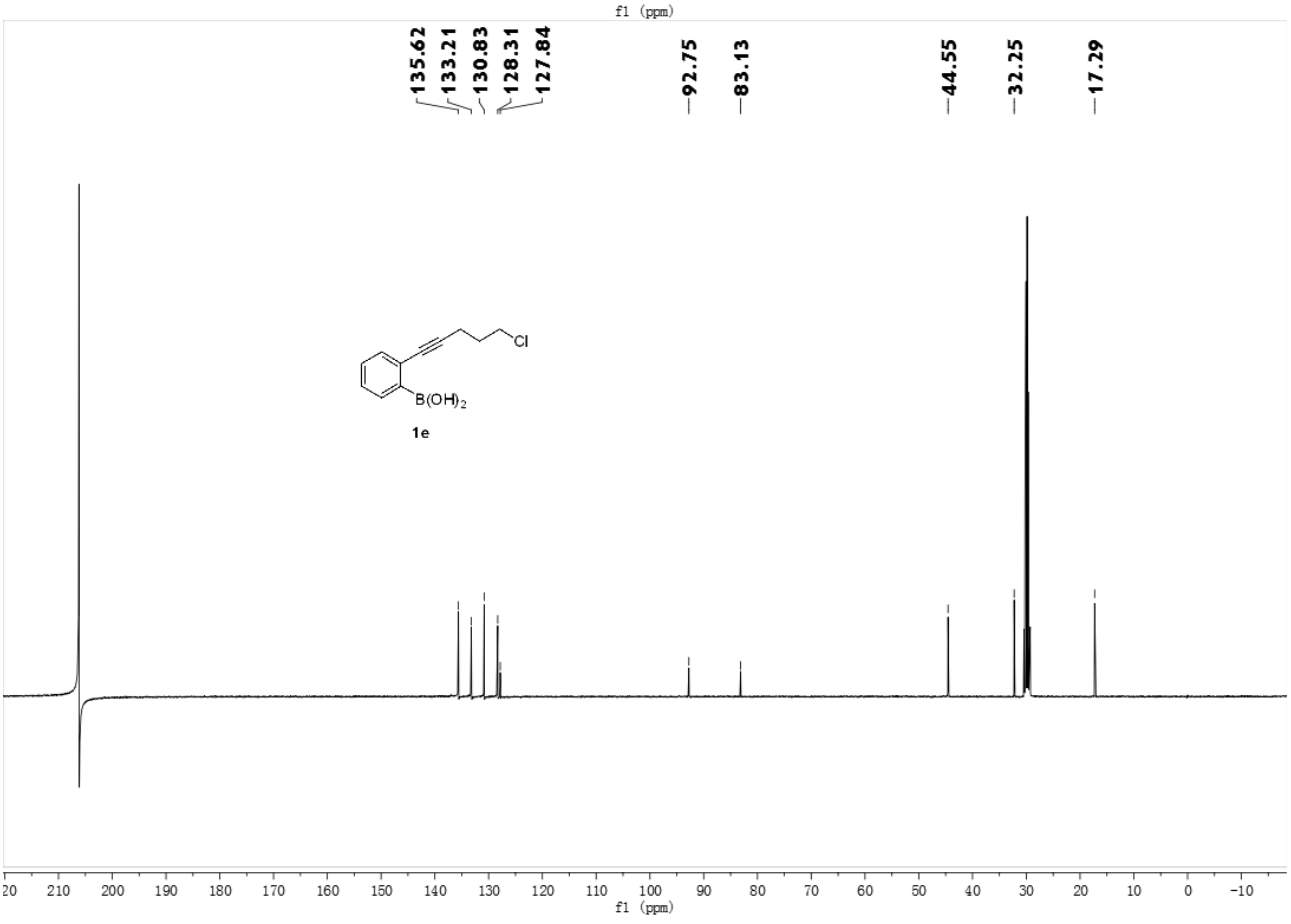

7.35
7.34
7.33
7.33
7.32
7.30
7.30
7.29
7.28
7.28
7.27
7.27
2.42
2.40
2.39
1.61
1.59
1.58
1.50
1.48
1.47
1.46
1.39
1.38
0.97
0.95
B(OH)2
1c
4.39
2.00
2.06
2.30
2.04
3.28
f1 (ppm)

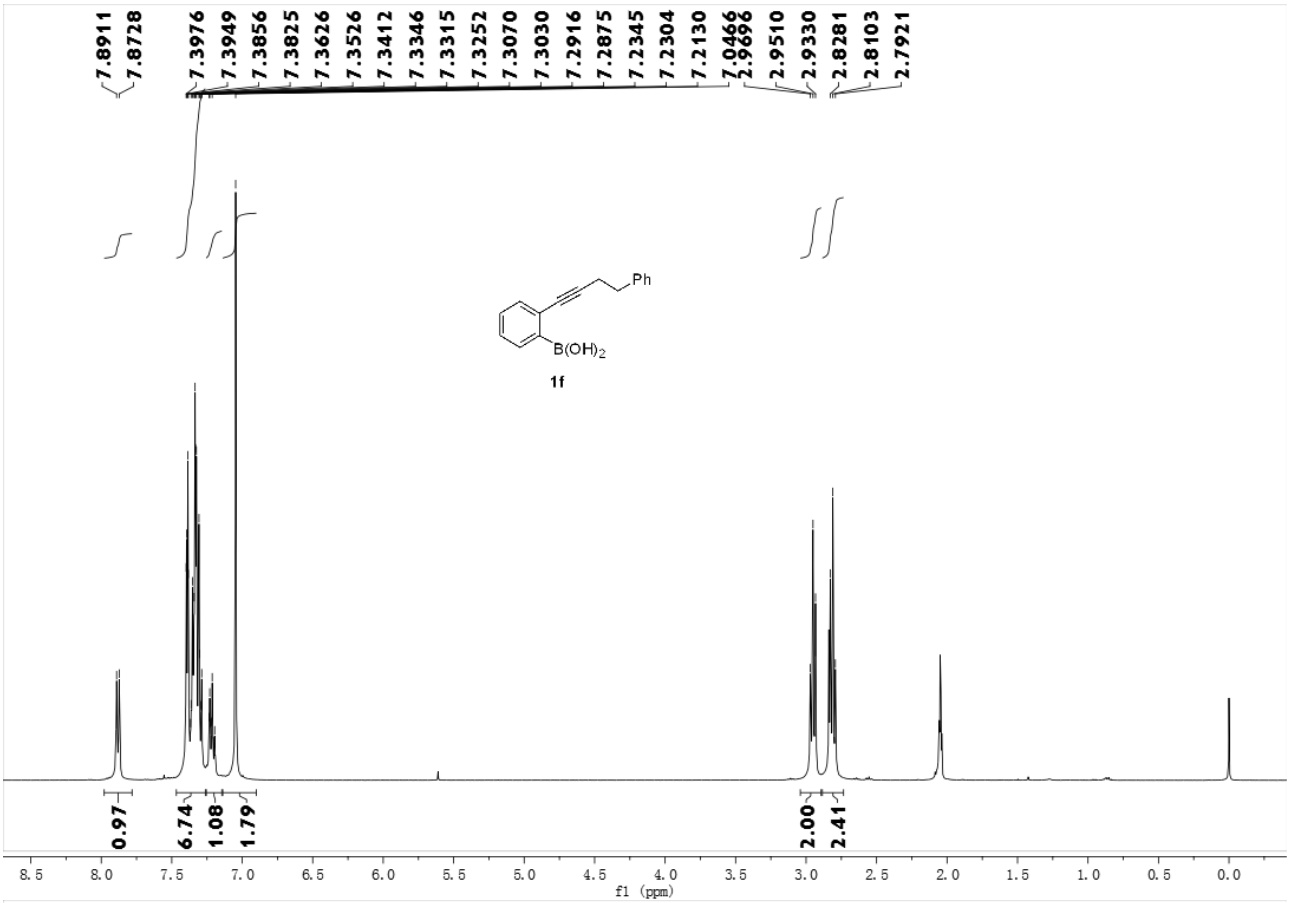

132.12
132.06
129.57
128.09
127.41
91.85
82.17
32.11
29.62
23.34
19.94
14.36
B(OH)2
1c

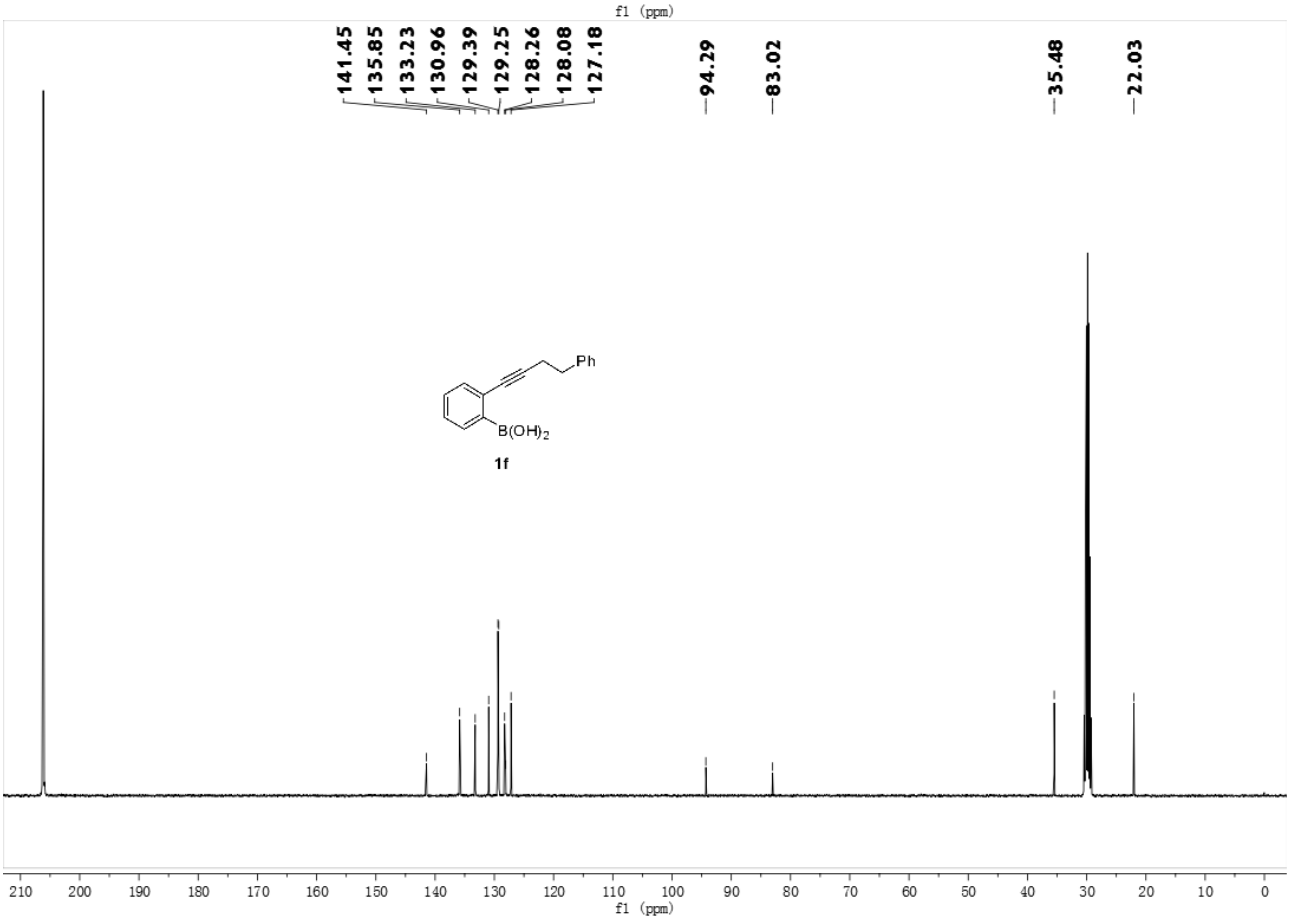

7.35
7.34
7.33
7.33
7.32
7.28
7.28
7.27
7.27
2.42
2.41
2.39
1.61
1.59
1.59
1.57
1.50
1.49
1.36
1.36
1.35
1.34
0.95
0.93
B(OH)2
1d
1.01
2.98
2.00
2.11
2.22
4.24
3.12
f1 (ppm)

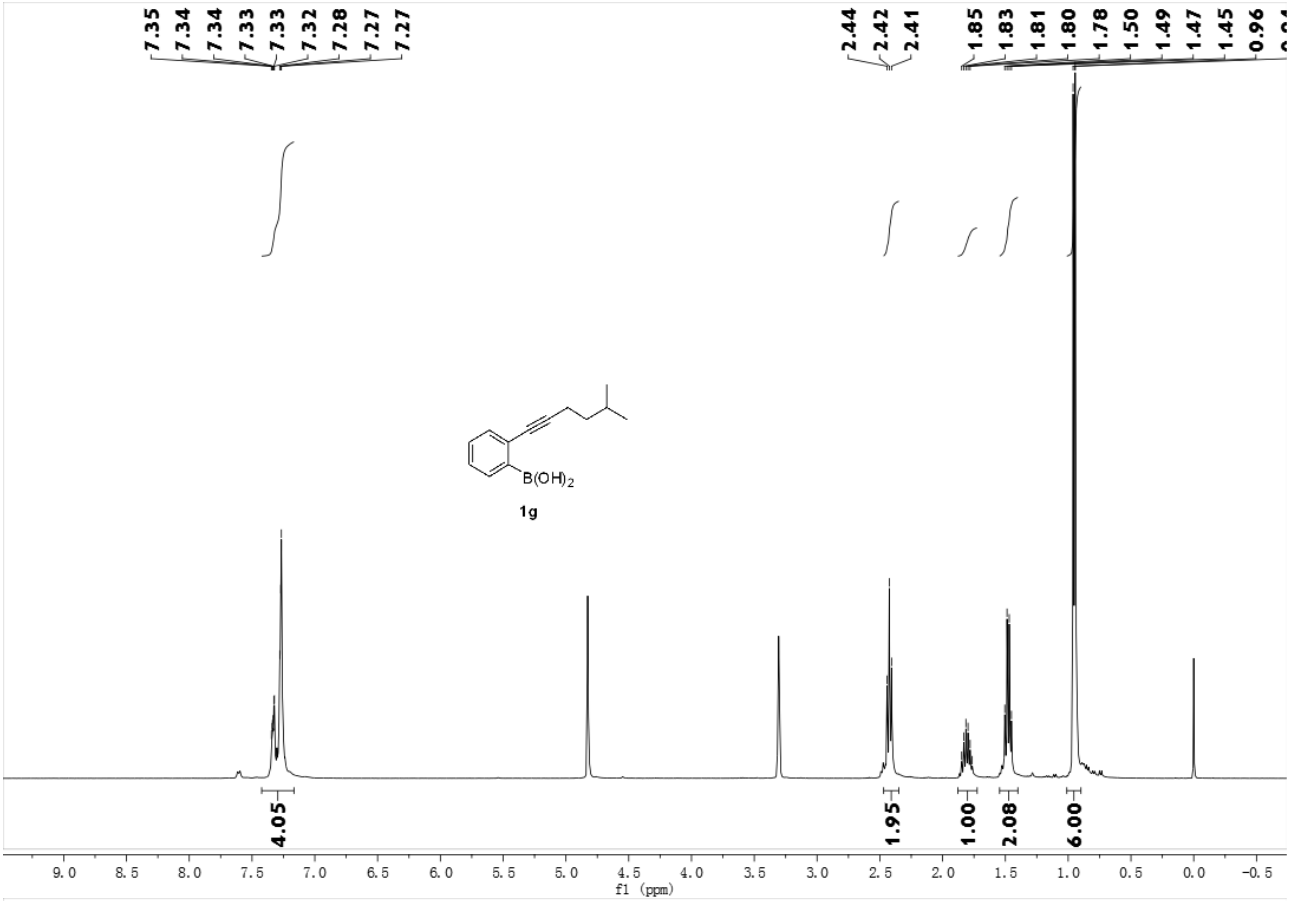

132.13
132.07
129.57
128.09
127.42
91.85
82.17
32.62
29.90
29.59
23.69
19.98
14.43
B(OH)2
1d
f1 (ppm)

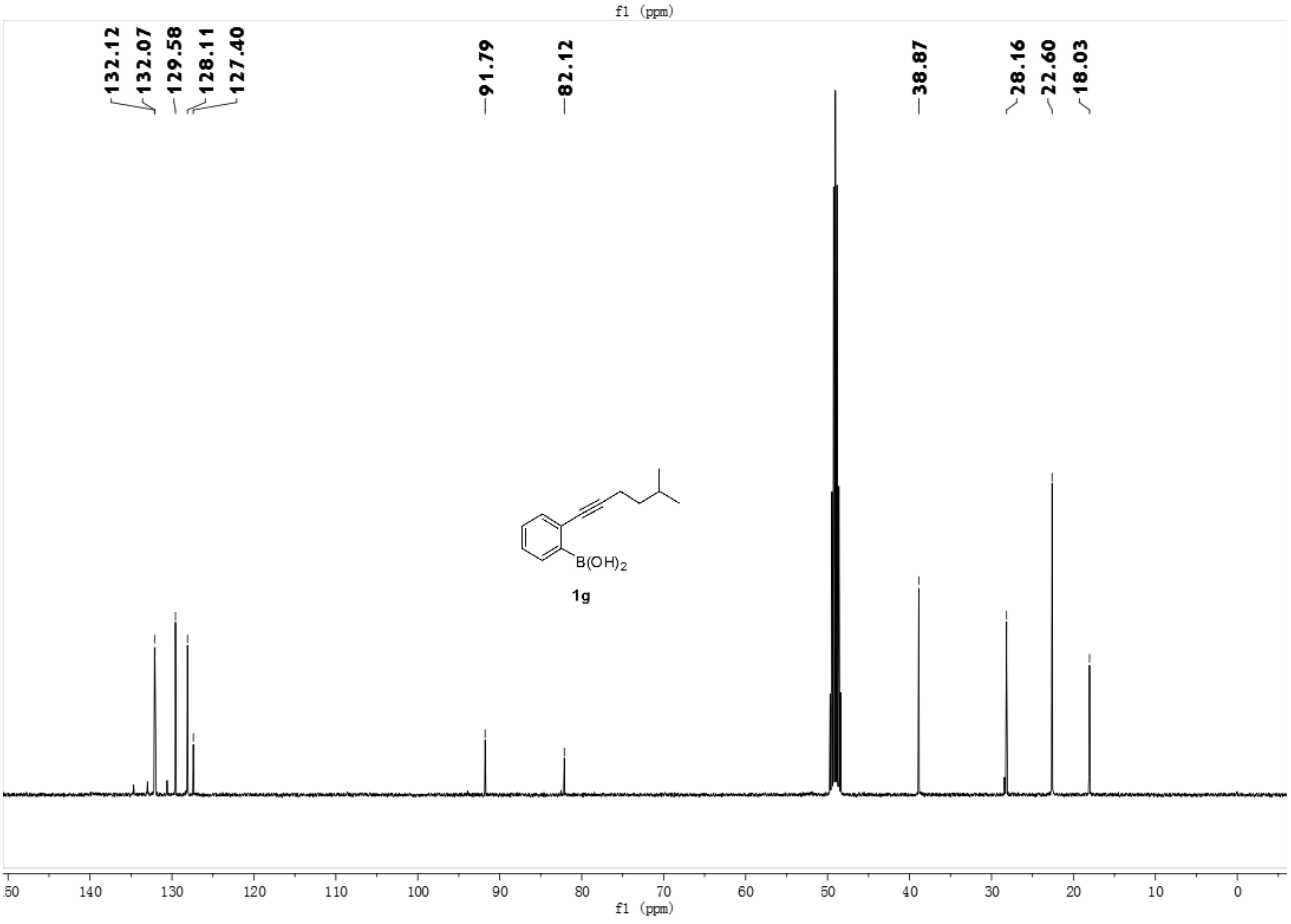

7.86
7.84
7.46
7.44
7.42
7.41
7.40
7.40
7.38
7.38
7.36
7.36
7.34
7.34
7.33
7.32
7.09
3.82
3.81
3.79
2.71
2.70
2.68
2.13
2.11
2.10
2.08
2.06
2.06
Cl
B(OH)2
1e
1.00
3.12
1.82
2.00
2.03
2.04
f1 (ppm)

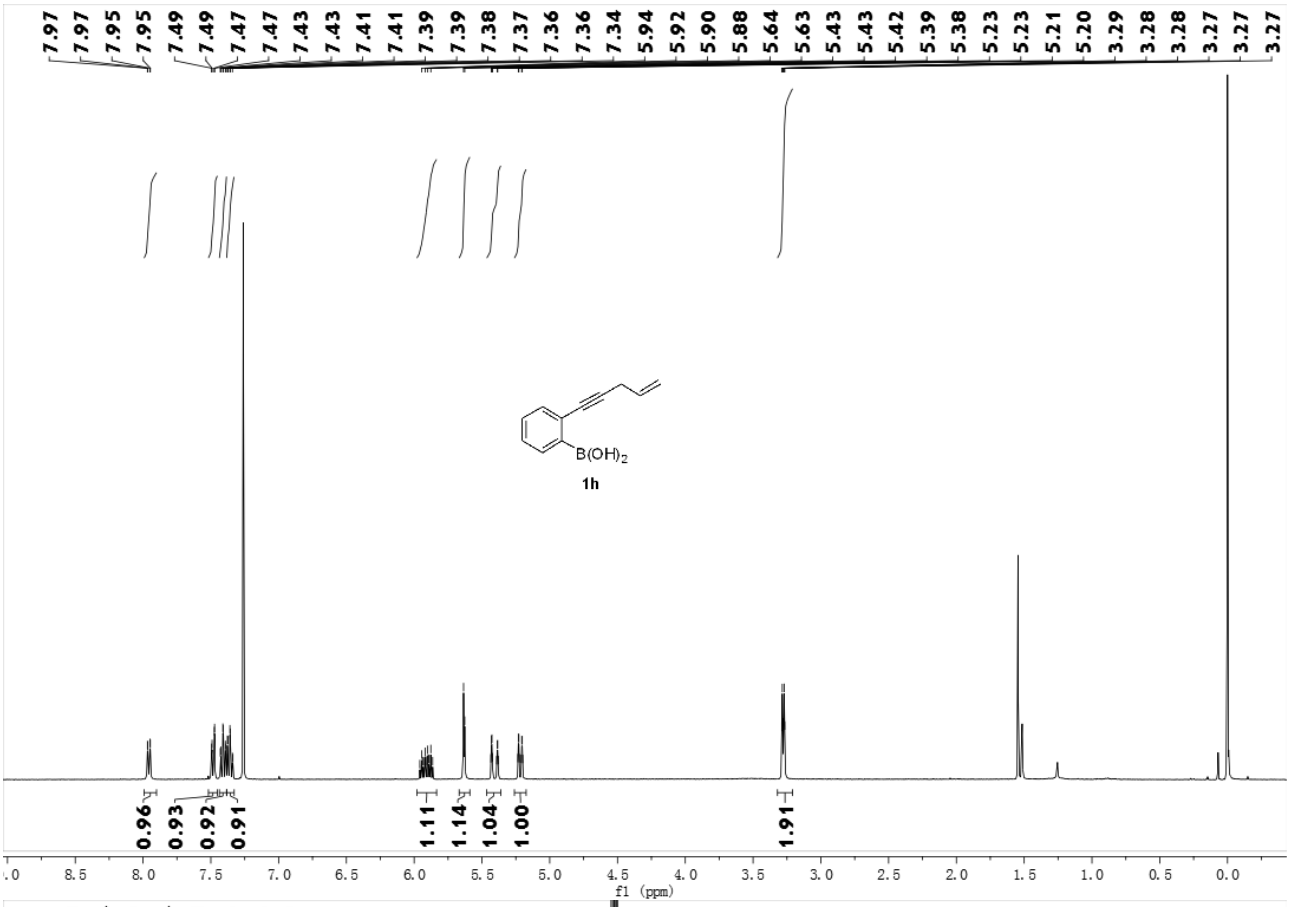

135.62
133.21
130.83
128.31
127.84
92.75
83.13
44.55
32.25
17.29
Cl
B(OH)2
1e
f1 (ppm)

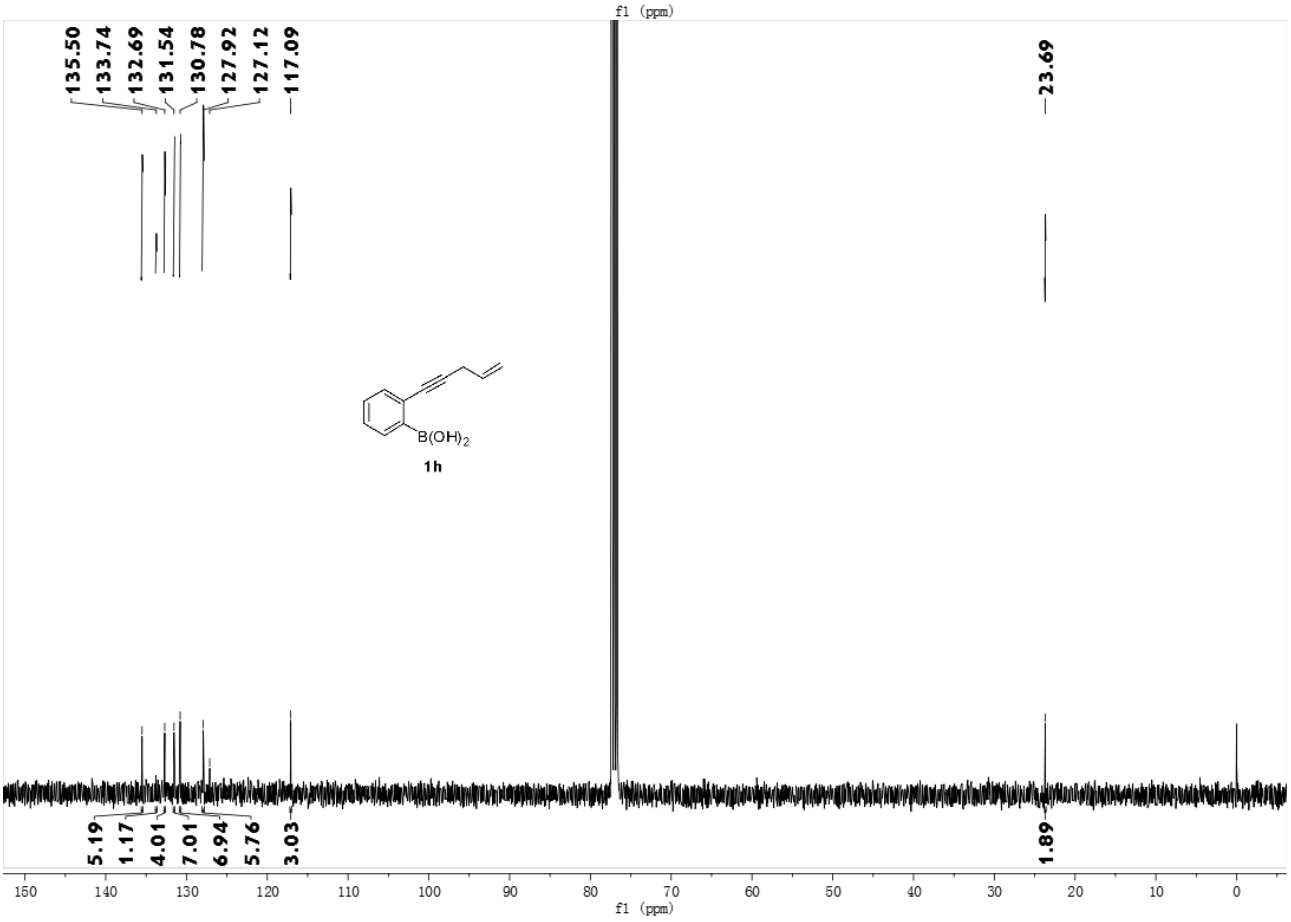

7.8911
7.8728
7.3976
7.3949
7.3856
7.3825
7.3626
7.3526
7.3412
7.3346
7.3315
7.3252
7.3070
7.3030
7.2916
7.2875
7.2345
7.2304
7.2130
7.0466
2.9696
2.9510
2.9330
2.8281
2.8103
2.7921
Ph
B(OH)2
1f
0.97
6.74
1.08
1.79
2.00
2.41
f1 (ppm)

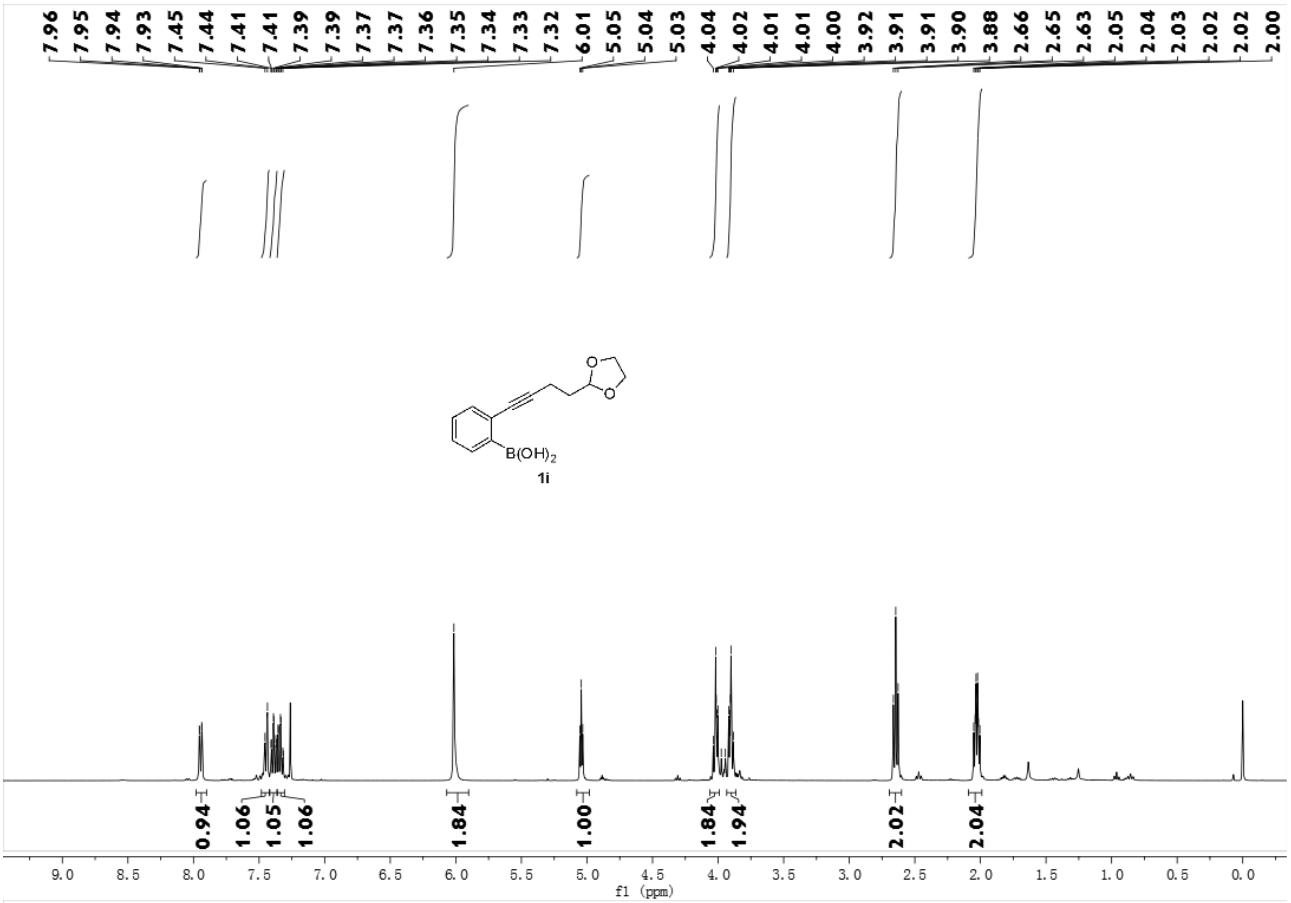

141.45
135.85
133.23
130.96
129.39
129.25
128.26
128.08
127.18
94.29
83.02
35.48
22.03
Ph
B(OH)2
1f
f1 (ppm)

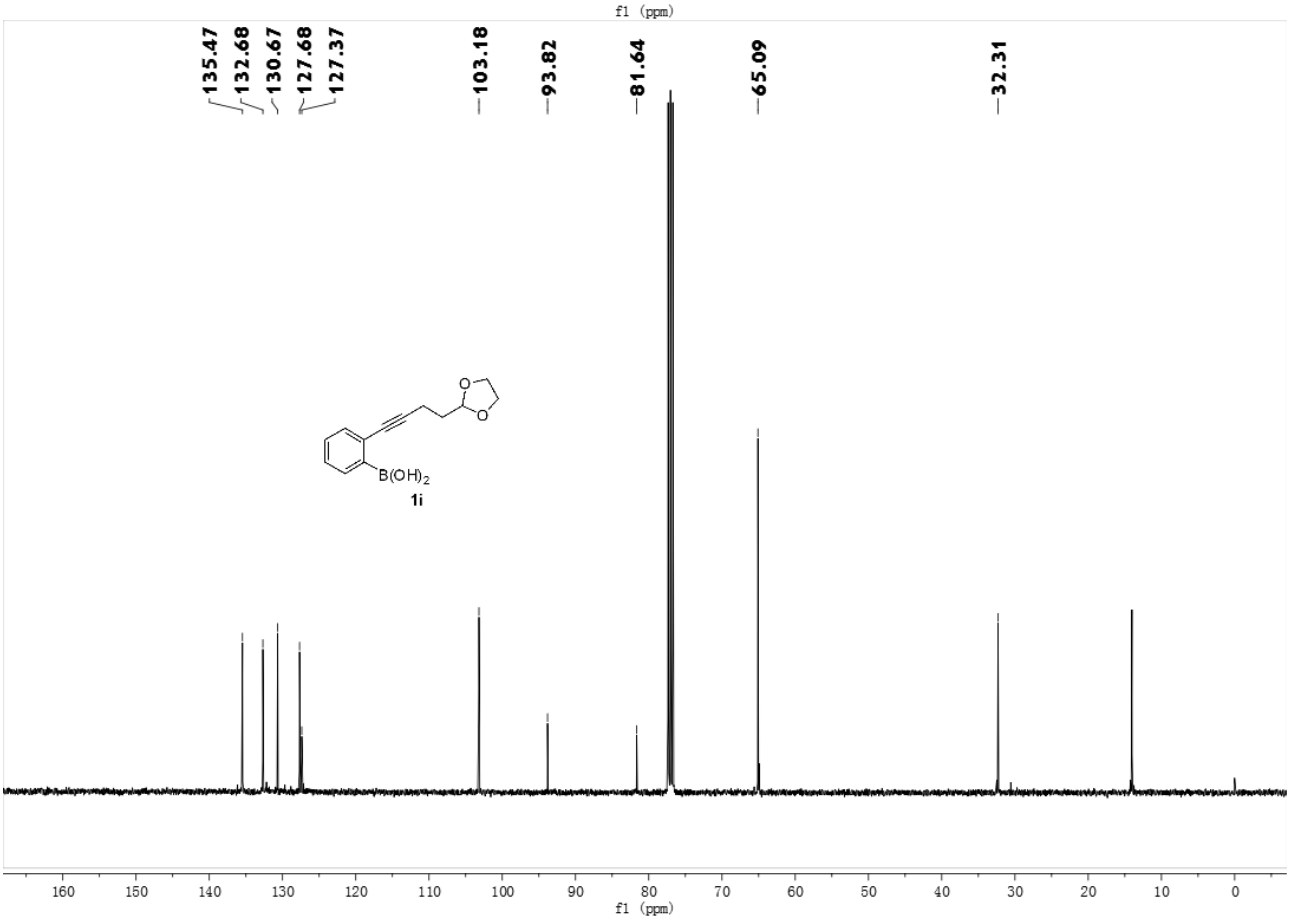

7.35
7.34
7.34
7.33
7.33
7.32
7.28
7.27
7.27
2.44
2.42
2.41
1.85
1.83
1.81
1.80
1.78
1.50
1.49
1.47
1.45
0.96
B(OH)2
1g
4.05
1.95
1.00
2.08
6.00
f1 (ppm)

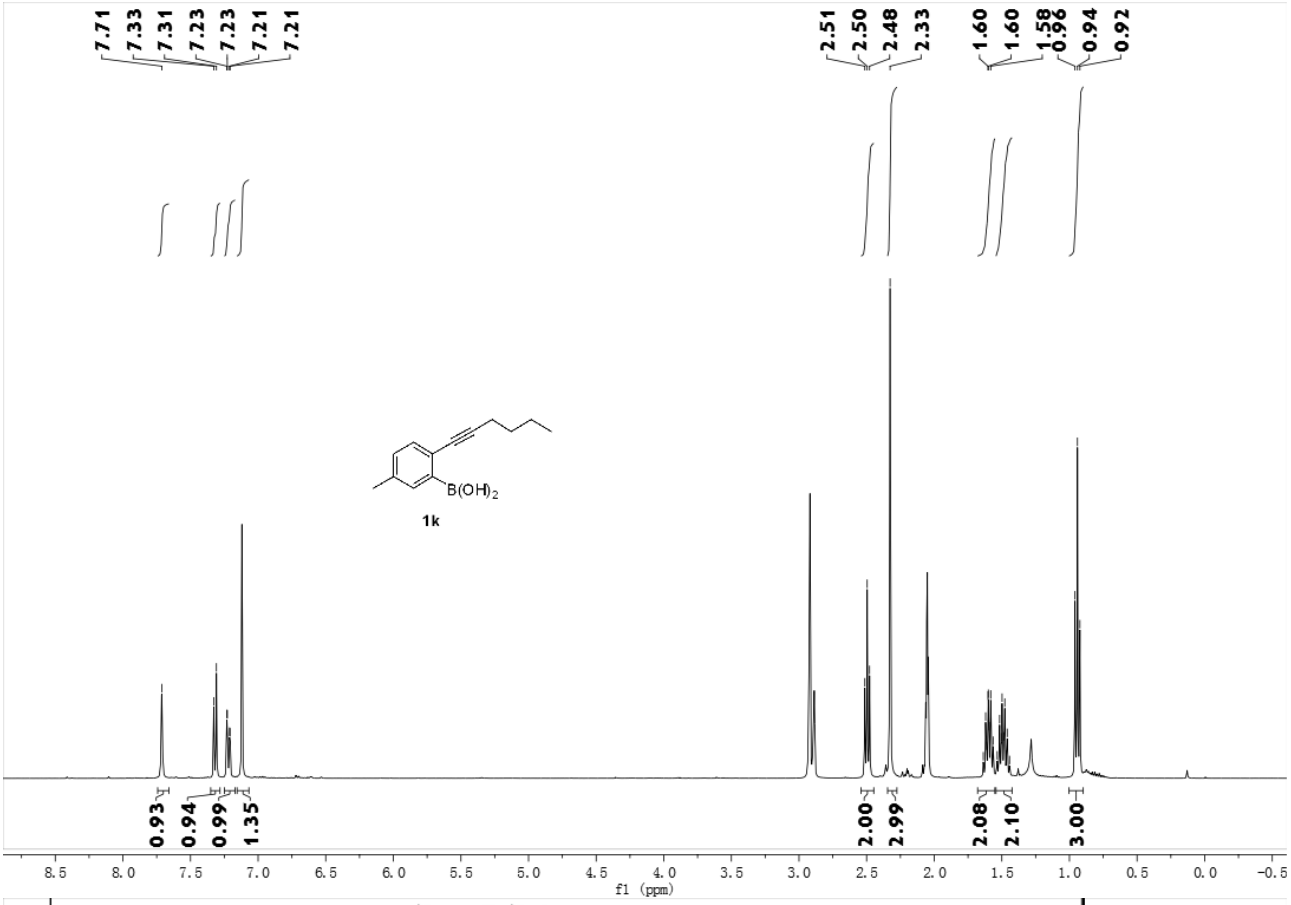

132.12
132.07
129.58
128.11
127.40
91.79
82.12
38.87
28.16
22.60
18.03
B(OH)2
1g
f1 (ppm)

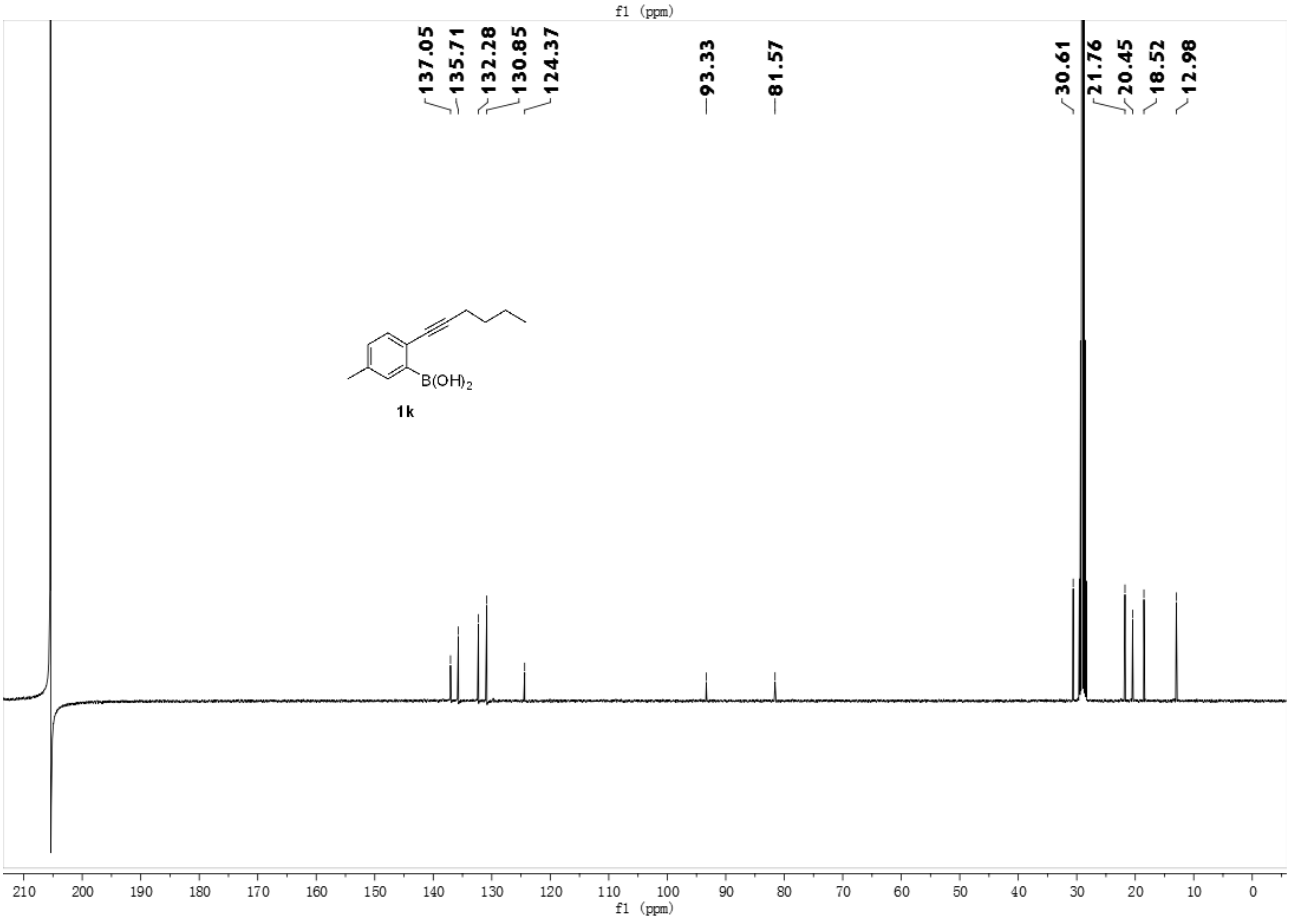

7.97 7.97 7.95 7.95 7.49 7.49 7.47 7.47 7.43 7.43 7.41 7.41 7.39 7.39 7.38 7.37 7.36 7.36 7.34 5.94 5.92 5.90 5.88 5.64 5.63 5.43 5.43 5.42 5.39 5.38 5.23 5.23 5.21 5.20 3.29 3.28 3.28 3.27 3.27 3.27
B(OH)2
1h
0.96 0.93 0.92 0.91 1.11 1.14 1.04 1.00 1.91
f1 (ppm)

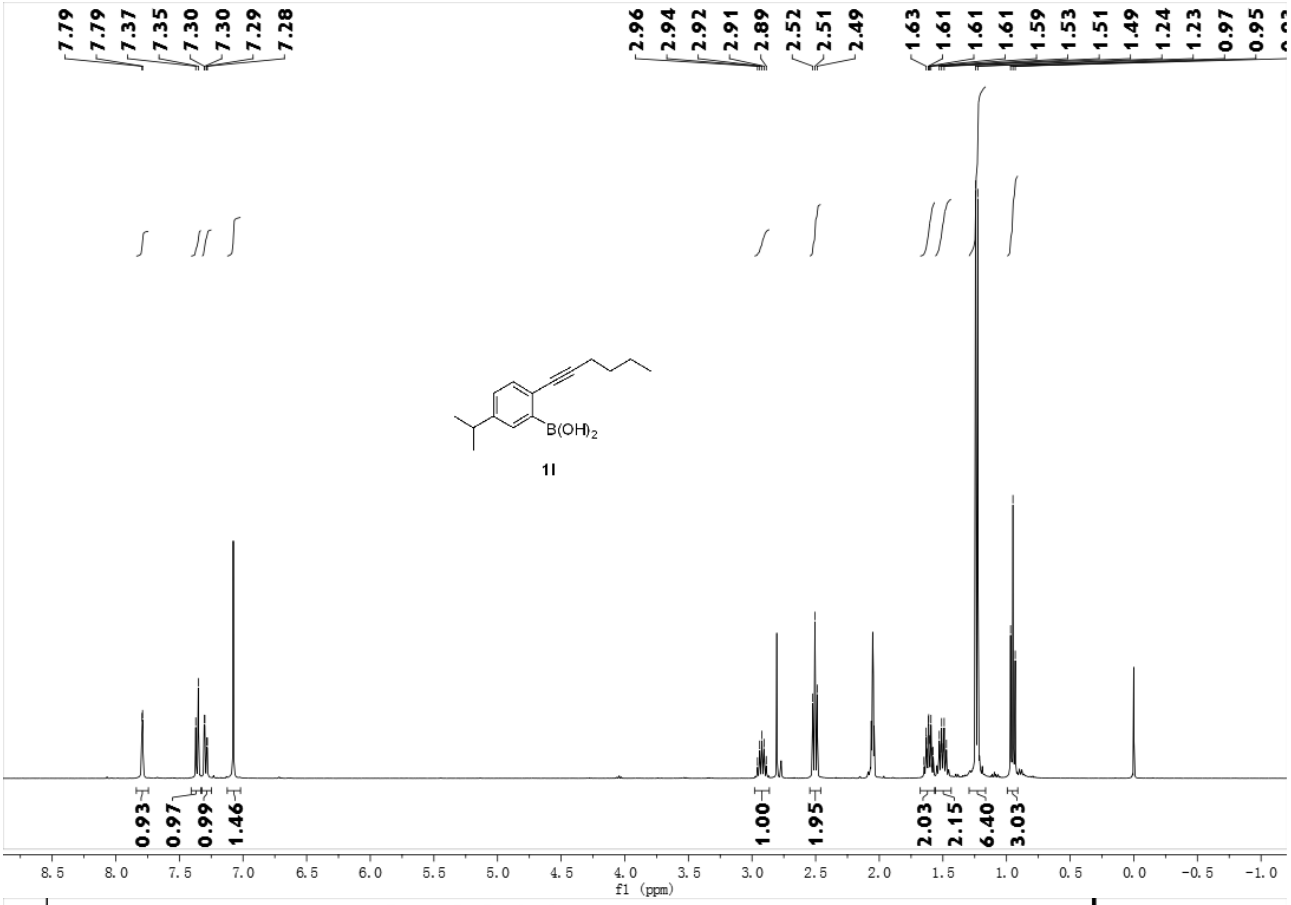

135.50 133.74 132.69 131.54 130.78 127.92 127.12 117.09
23.69
B(OH)2
1h
5.19 1.17 4.01 7.01 6.94 5.76 3.03 1.89
f1 (ppm)

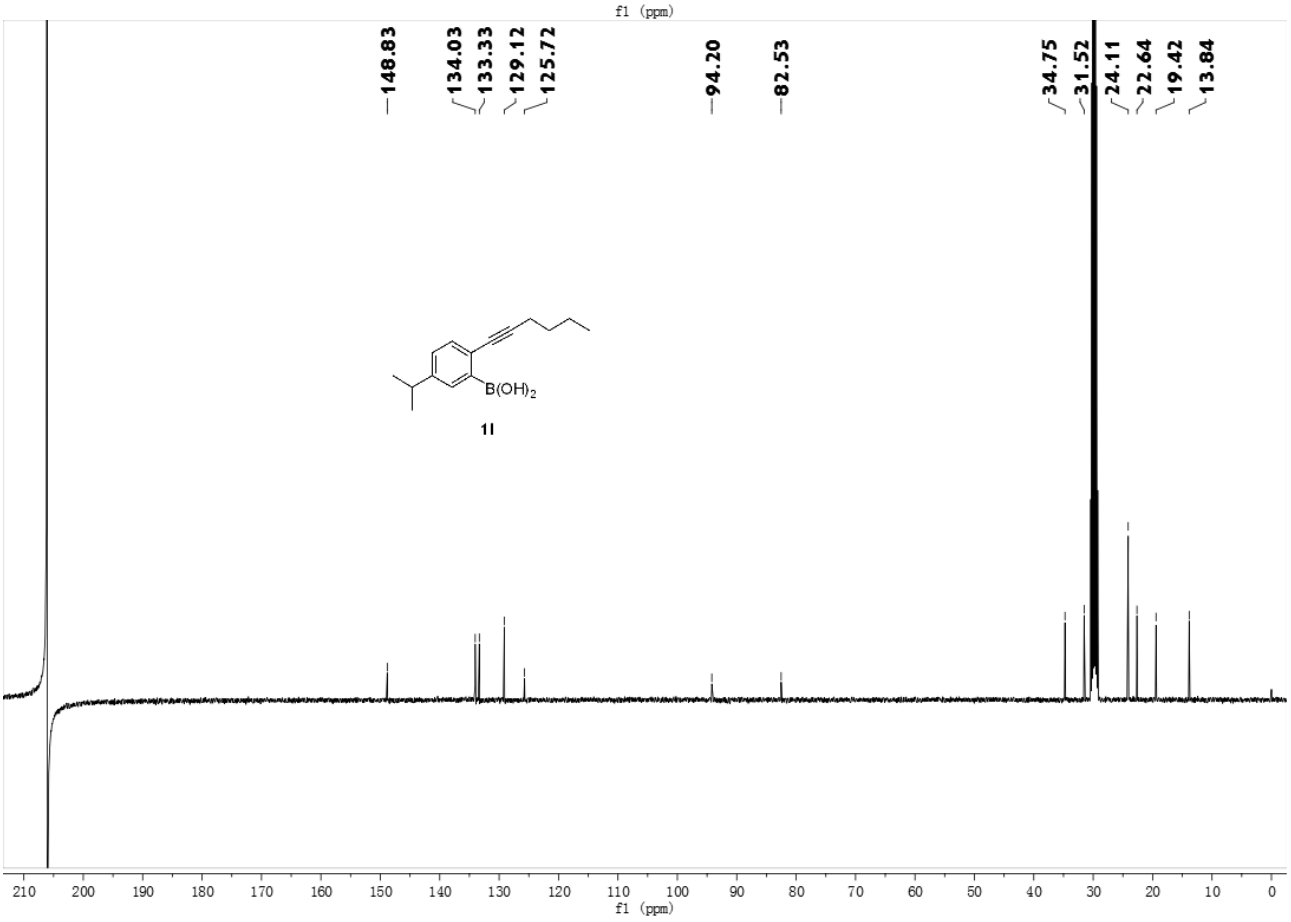

7.96 7.95 7.94 7.93 7.45 7.44 7.41 7.41 7.39 7.39 7.37 7.37 7.36 7.35 7.34 7.33 7.32 6.01 5.05 5.04 5.03 4.04 4.02 4.01 4.01 4.00 3.92 3.91 3.91 3.90 3.88 2.66 2.65 2.63 2.05 2.04 2.03 2.02 2.02 2.00
B(OH)2
1i
0.94 1.06 1.05 1.06 1.84 1.00 1.84 1.94 2.02 2.04
f1 (ppm)

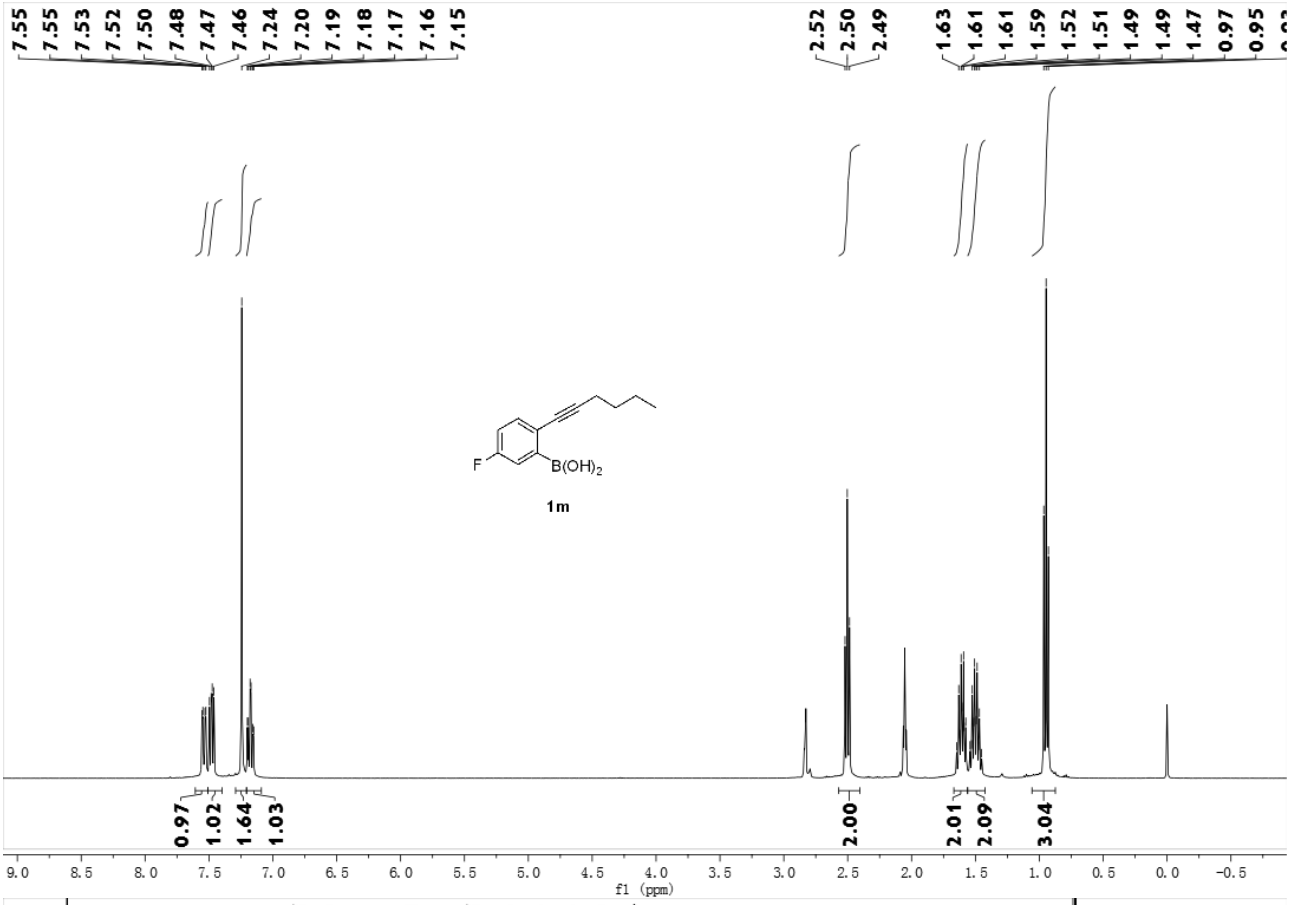

135.47 132.68 130.67 127.68 127.37 103.18 93.82 81.64 65.09 32.31
B(OH)2
1i
f1 (ppm)

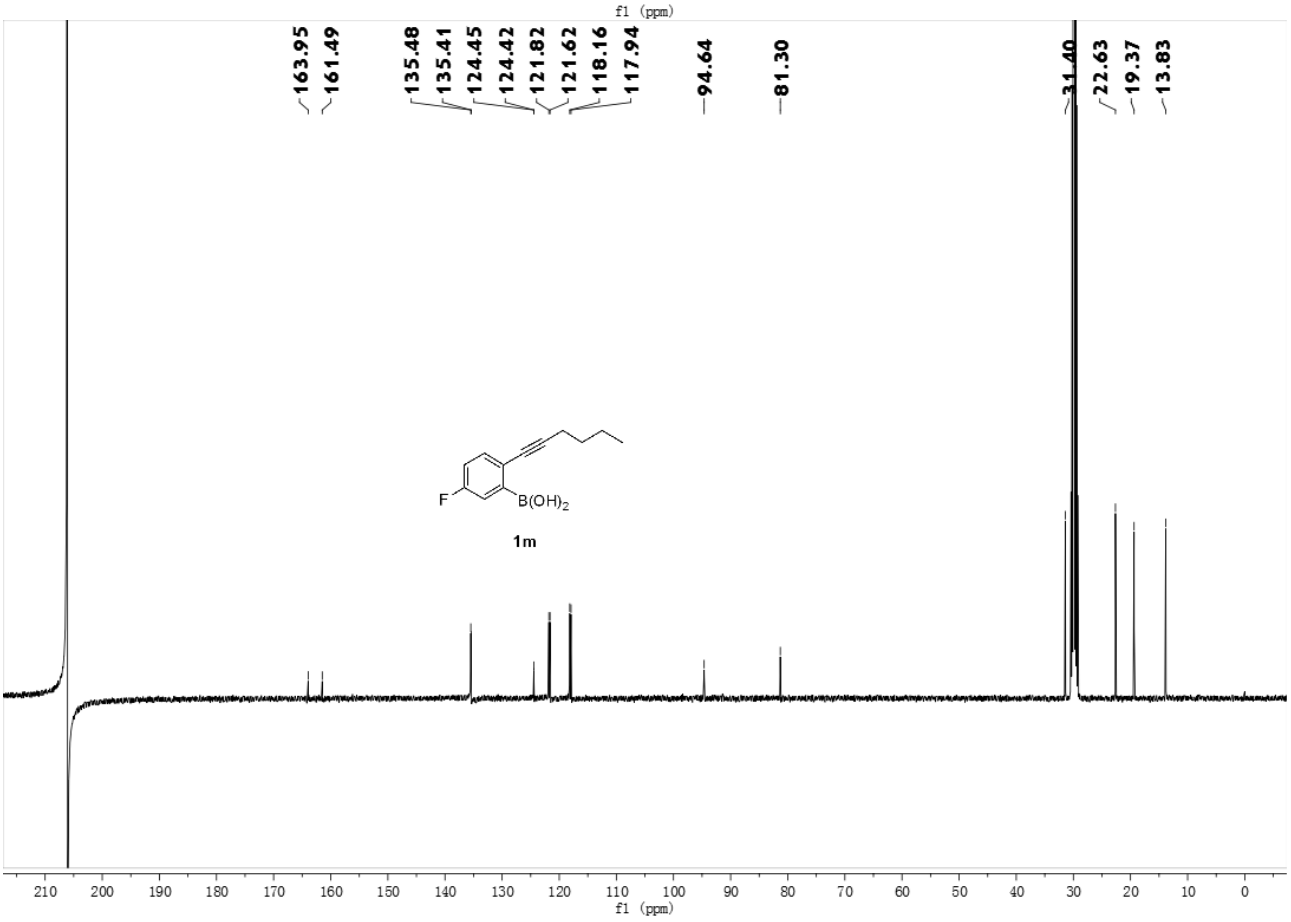

7.71
7.33
7.31
7.23
7.23
7.21
7.21
2.51
2.50
2.48
2.33
1.60
1.60
1.58
0.96
0.94
0.92
B(OH)2
1k
0.93
0.94
0.99
1.35
2.00
2.99
2.08
2.10
3.00
f1 (ppm)

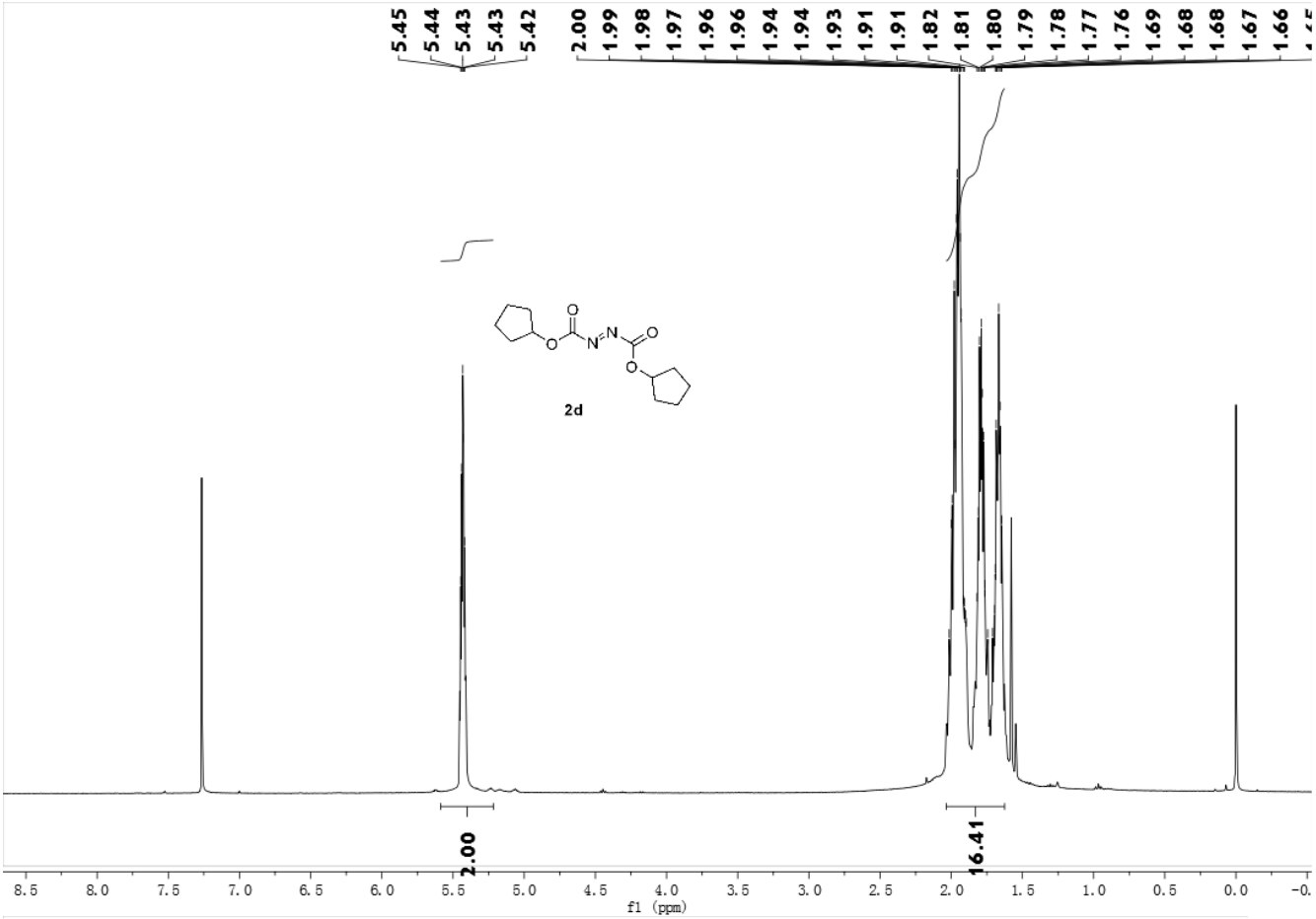

137.05
135.71
132.28
130.85
124.37
93.33
81.57
30.61
21.76
20.45
18.52
12.98
B(OH)2
1k
f1 (ppm)

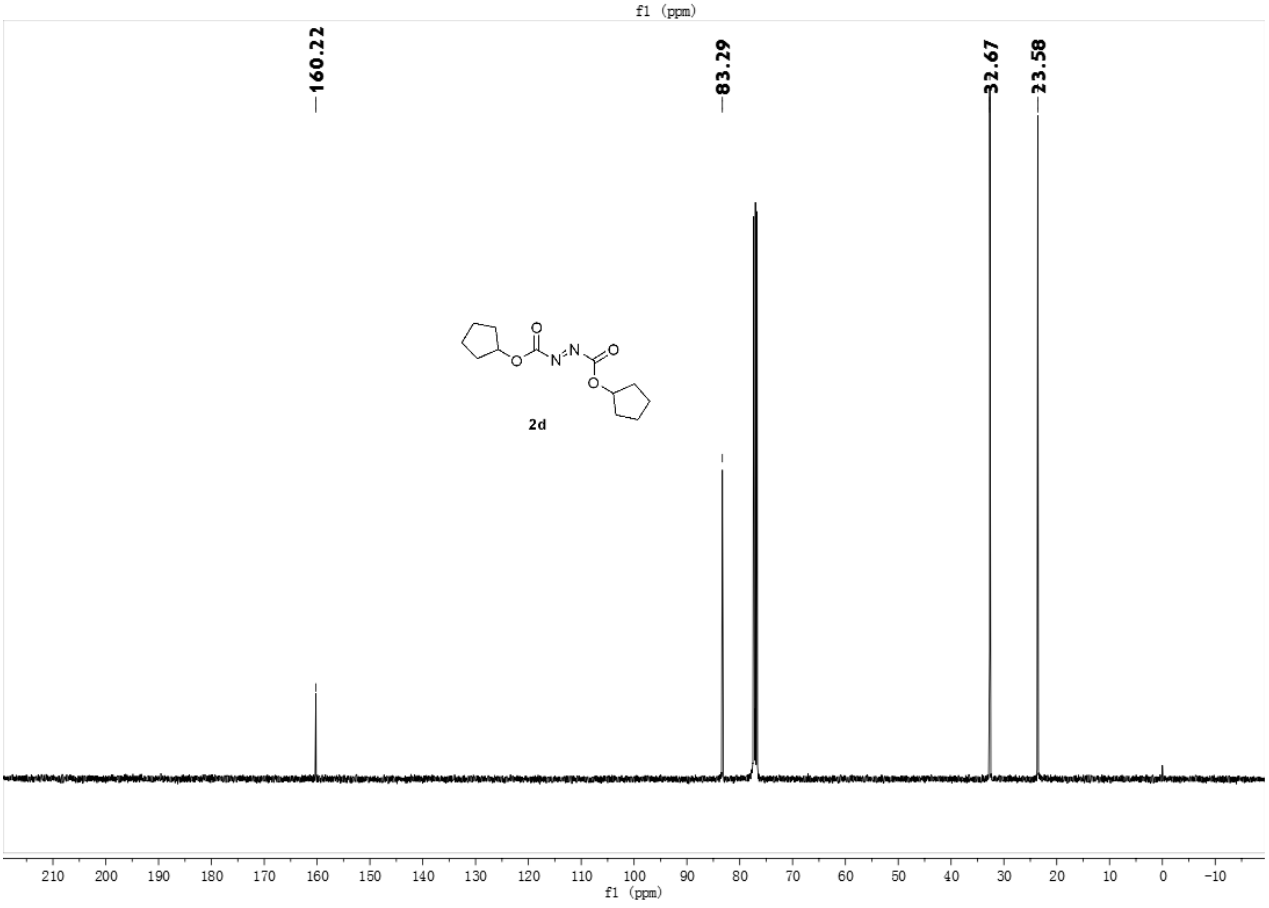

7.79
7.79
7.37
7.35
7.30
7.30
7.29
7.28
2.96
2.94
2.92
2.91
2.89
2.52
2.51
2.49
1.63
1.61
1.61
1.61
1.59
1.53
1.51
1.49
1.24
1.23
0.97
0.95
B(OH)2
1l
0.93
0.97
0.99
1.46
1.00
1.95
2.03
2.15
6.40
3.03
f1 (ppm)

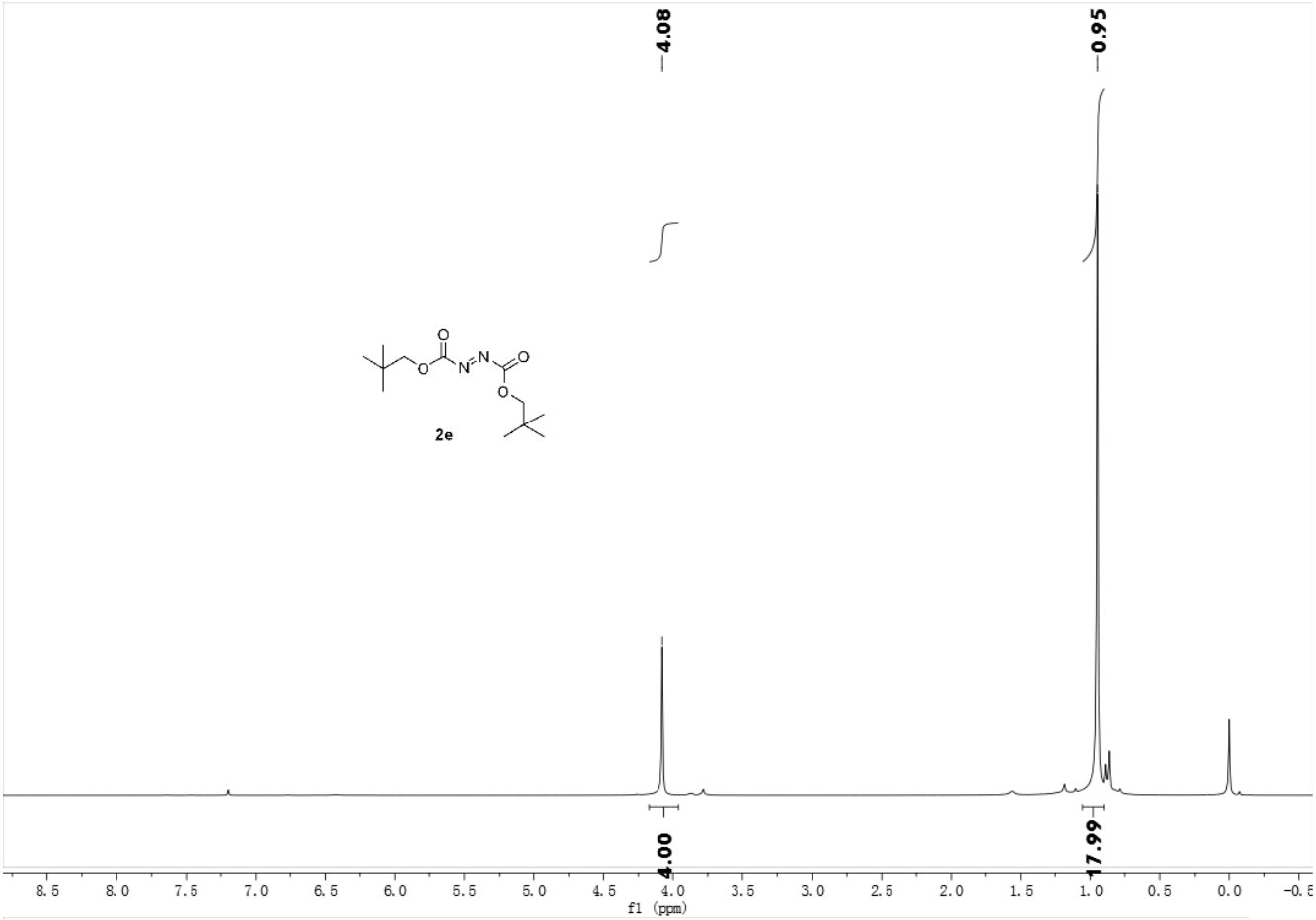

148.83
134.03
133.33
129.12
125.72
94.20
82.53
34.75
31.52
24.11
22.64
19.42
13.84
B(OH)2
1l
f1 (ppm)

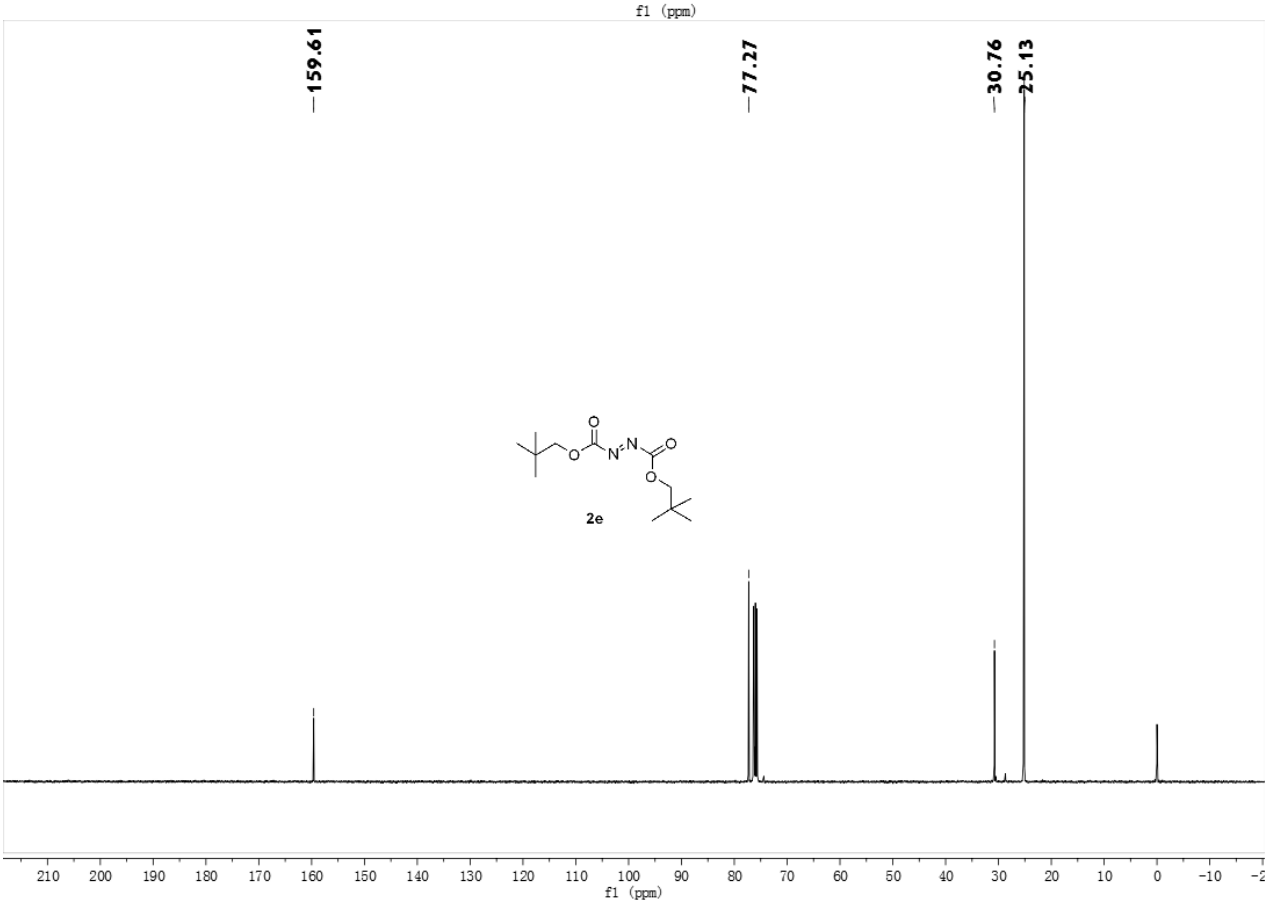

7.55
7.55
7.53
7.52
7.50
7.48
7.47
7.46
7.24
7.20
7.19
7.18
7.17
7.16
7.15
2.52
2.50
2.49
1.63
1.61
1.61
1.59
1.52
1.51
1.49
1.49
1.47
0.97
0.95
F
B(OH)2
1m
0.97
1.02
1.64
1.03
2.00
2.01
2.09
3.04
f1 (ppm)

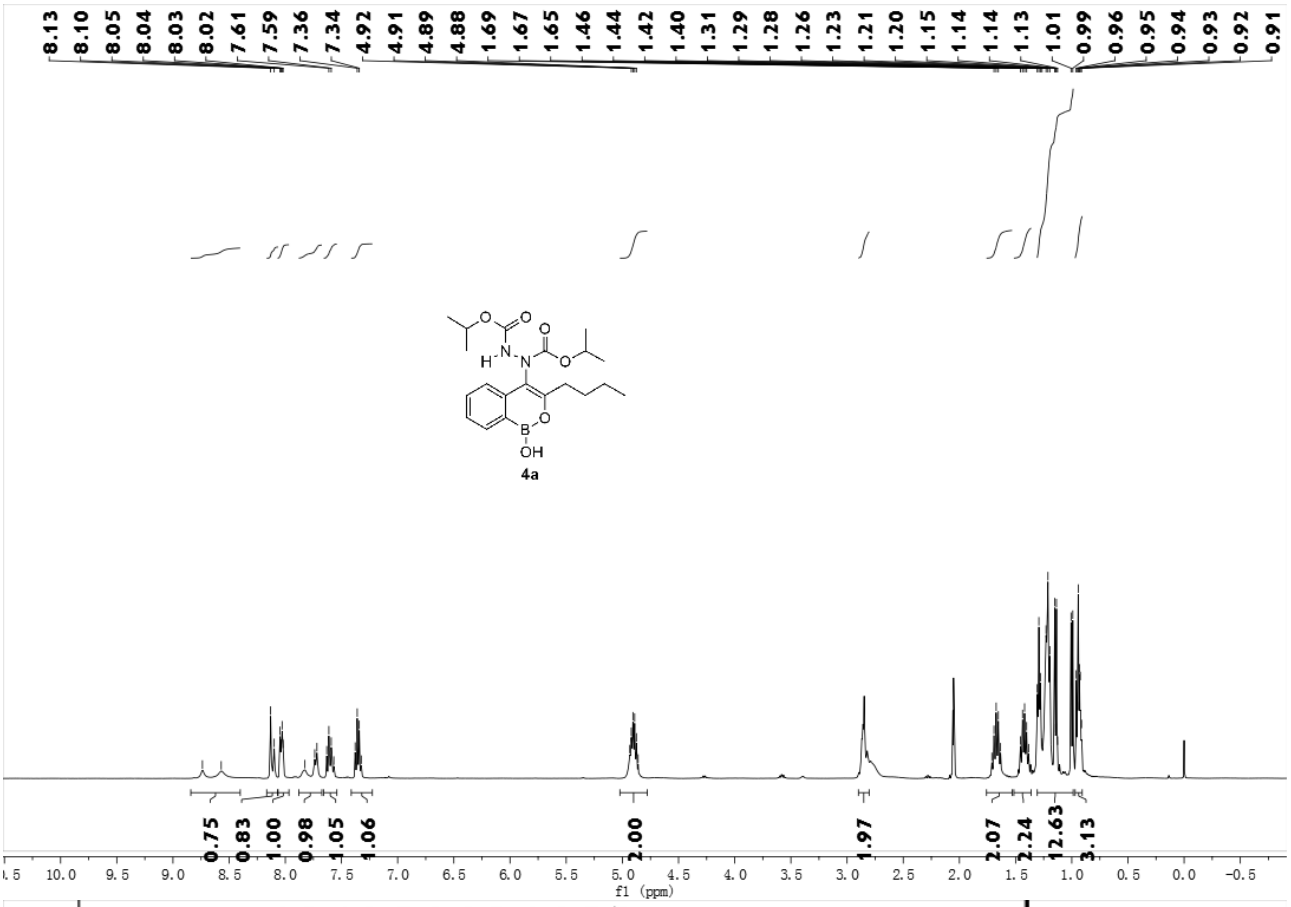

163.95
161.49
135.48
135.41
124.45
124.42
121.82
121.62
118.16
117.94
94.64
81.30
31.40
22.63
19.37
13.83
F
B(OH)2
1m
f1 (ppm)

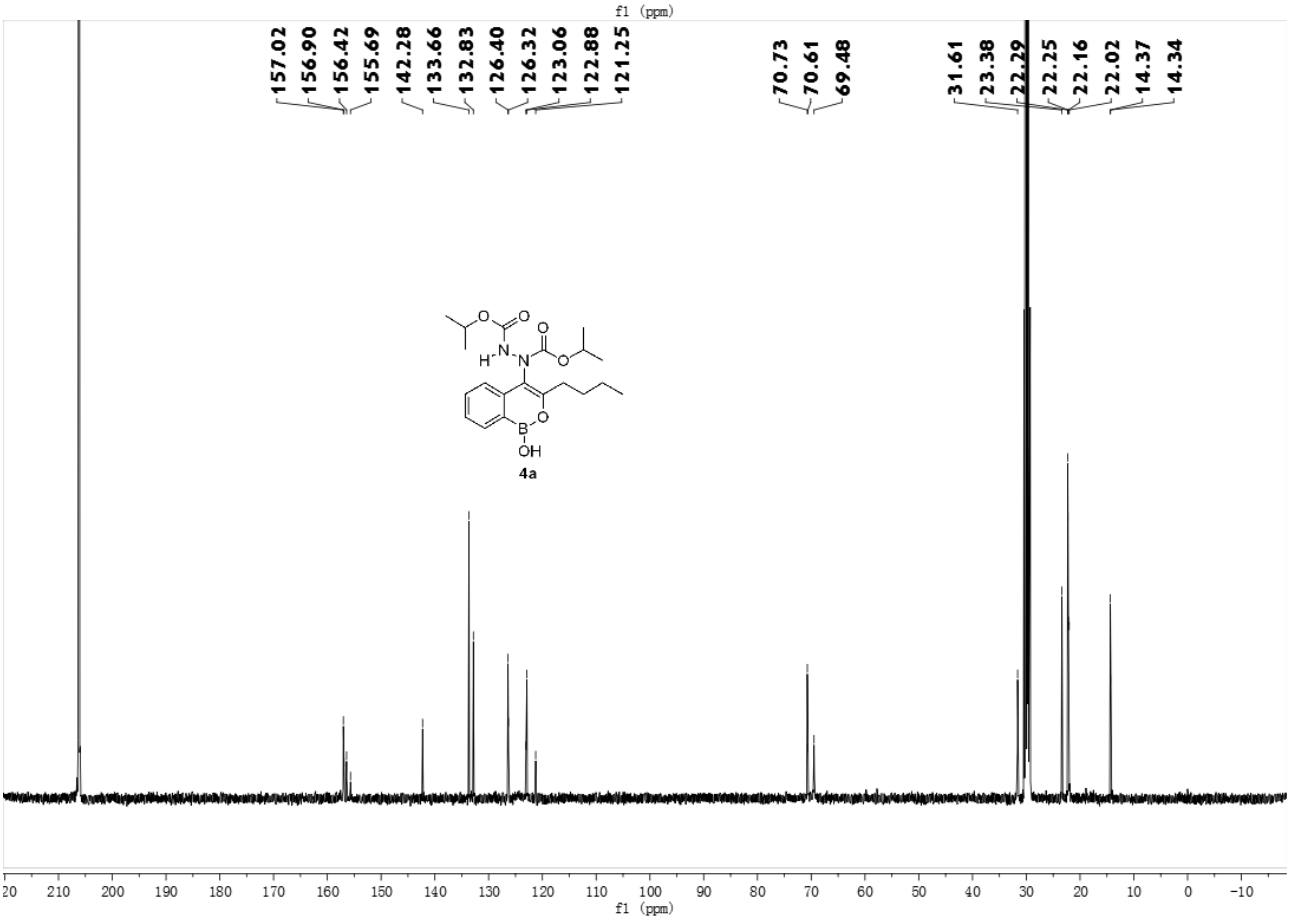

5.45
5.44
5.43
5.43
5.42
2.00
1.99
1.98
1.97
1.96
1.96
1.94
1.94
1.93
1.91
1.91
1.82
1.81
1.80
1.79
1.78
1.77
1.76
1.69
1.68
1.68
1.67
1.66
2d
2.00
16.41
f1 (ppm)

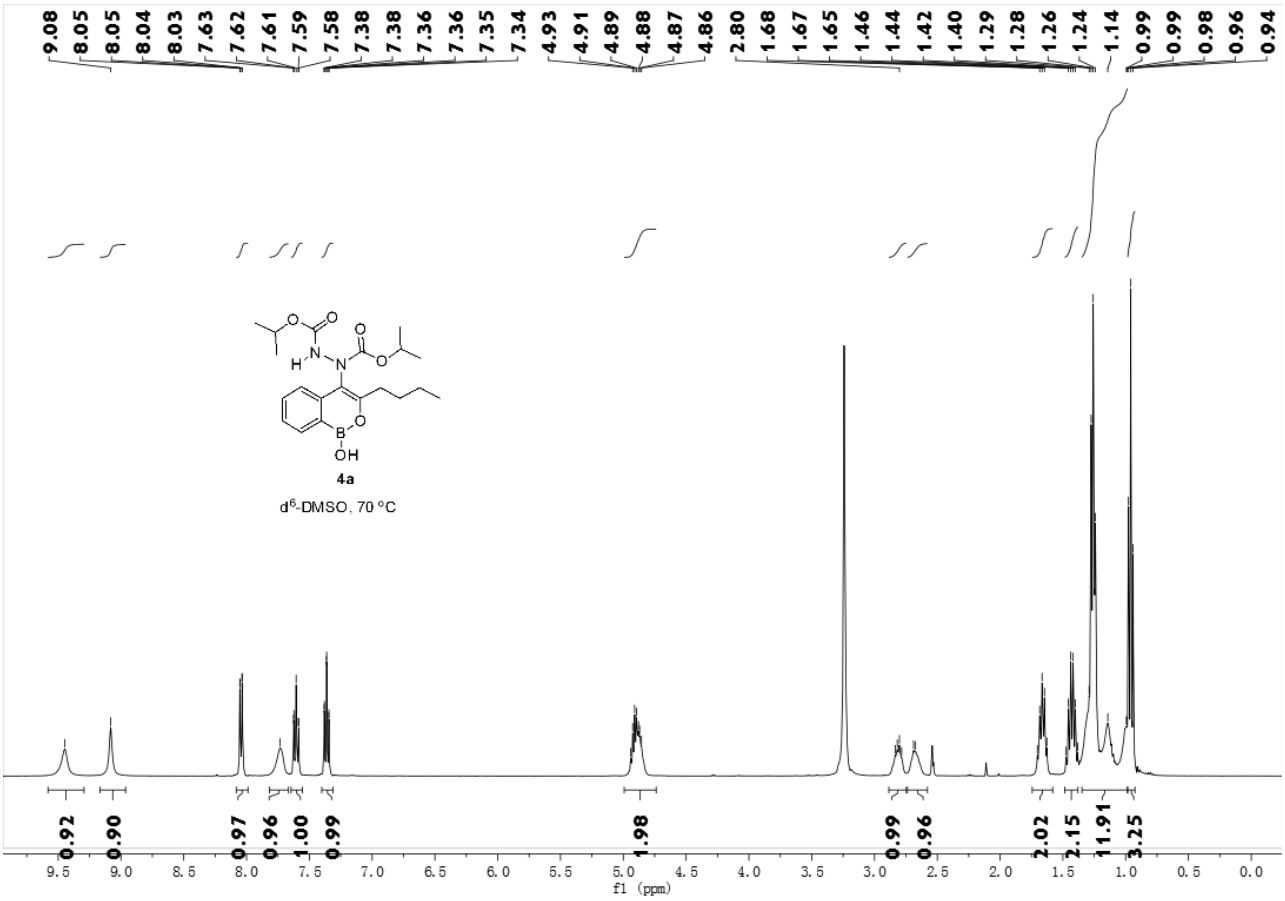

160.22
83.29
32.67
23.58
2d
f1 (ppm)

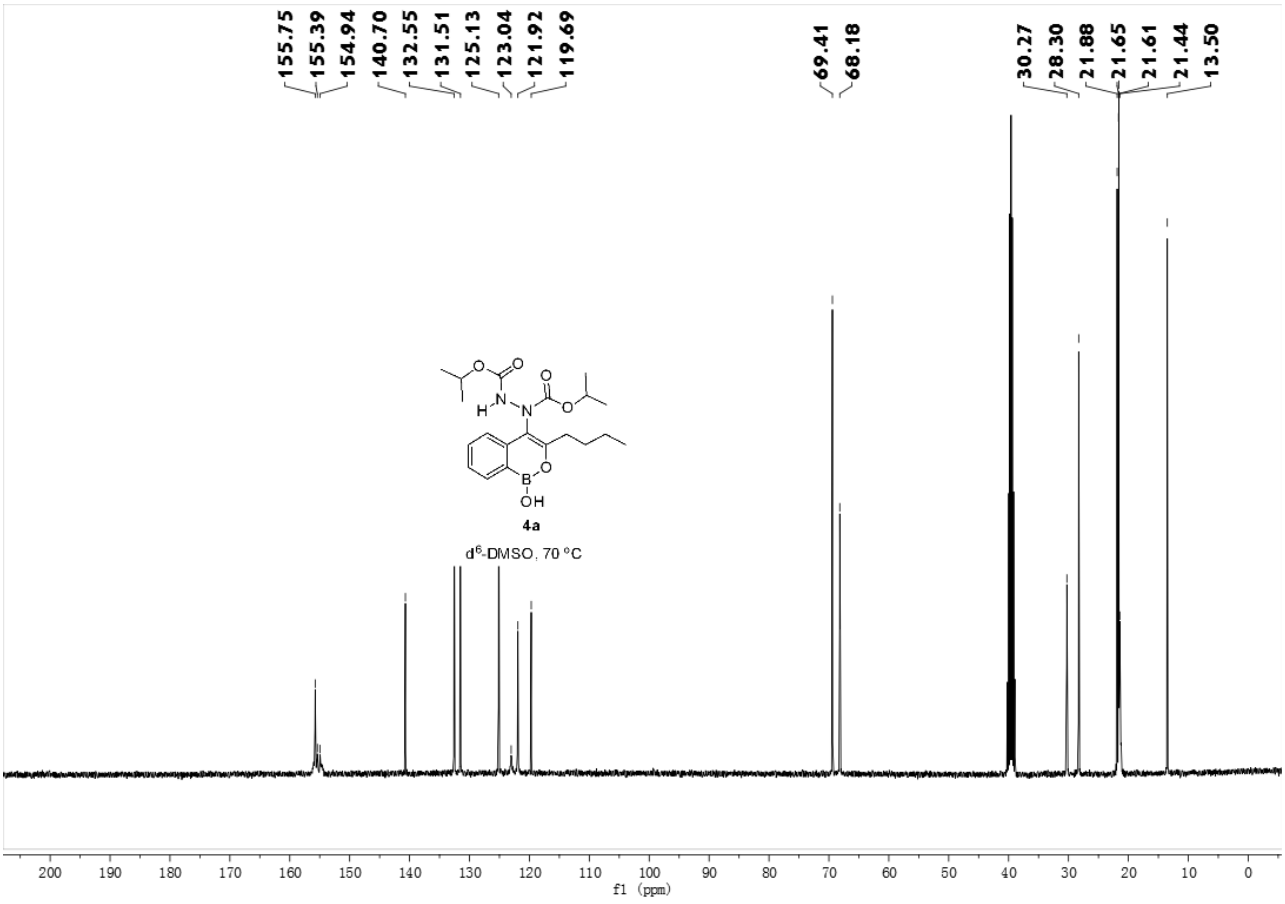

4.08
0.95
2e
4.00
17.99
f1 (ppm)

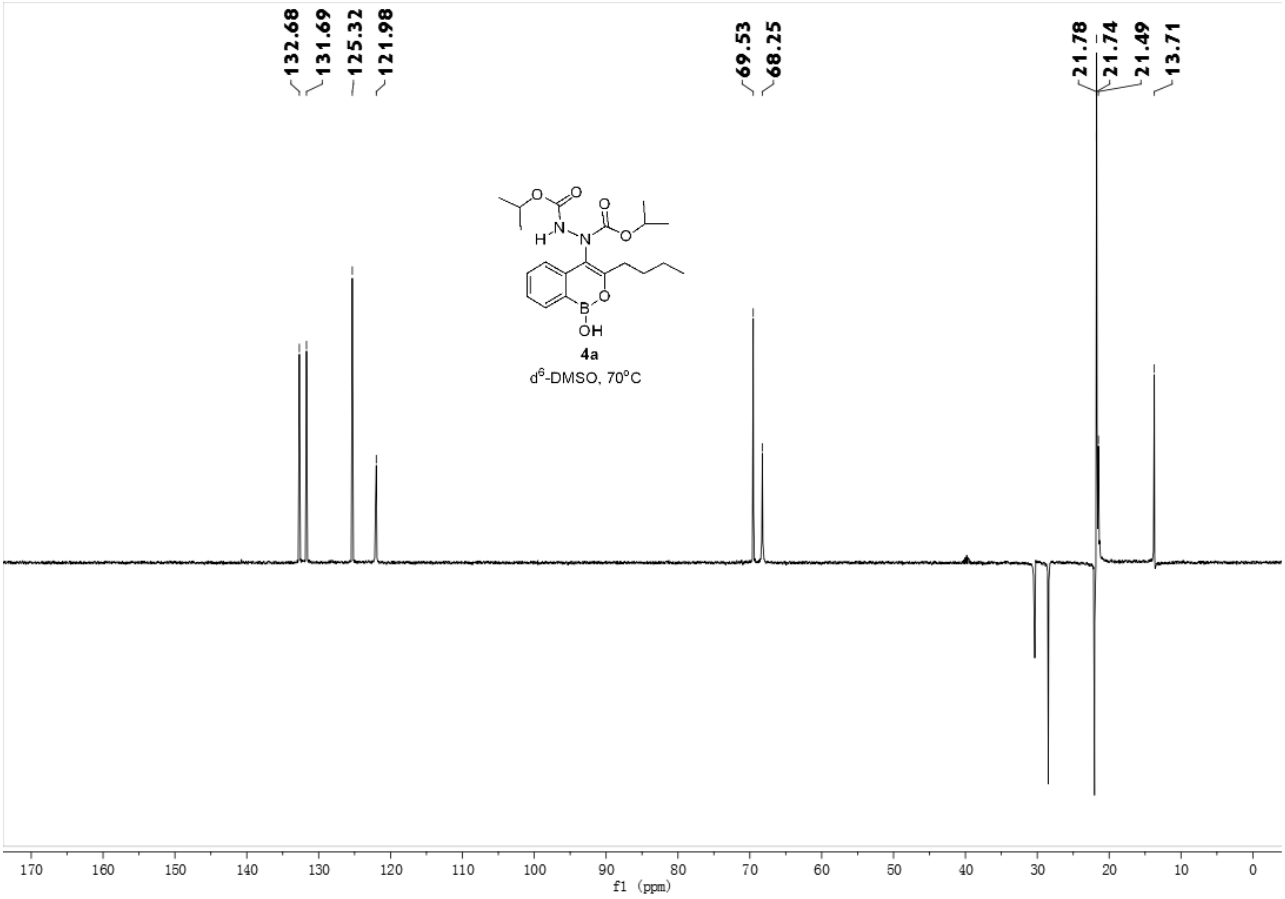

159.61
77.27
30.76
25.13
2e
f1 (ppm)

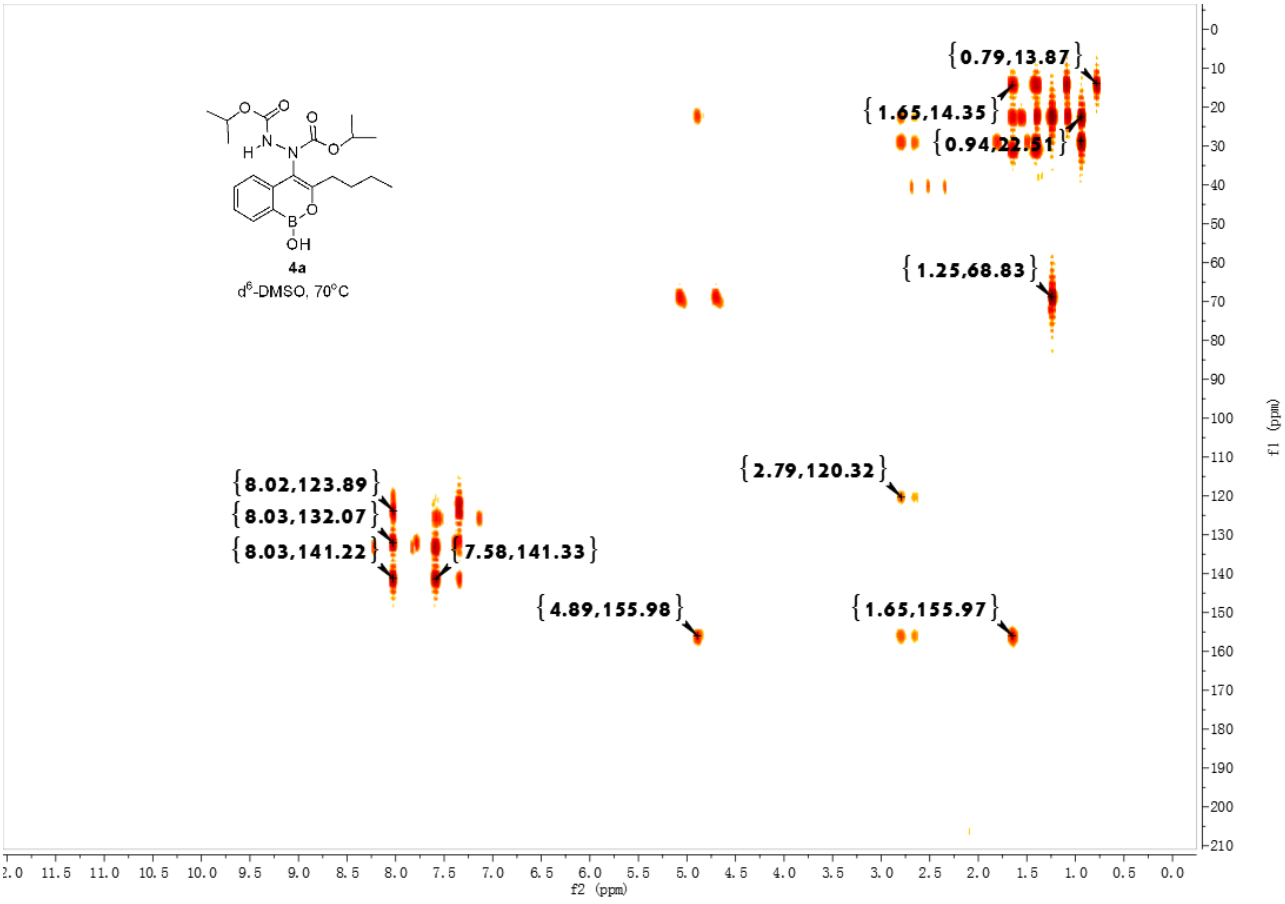

8.13 8.10 8.05 8.04 8.03 8.02 7.61 7.59 7.36 7.34 4.92 4.91 4.89 4.88 1.69 1.67 1.65 1.46 1.44 1.42 1.40 1.31 1.29 1.28 1.26 1.23 1.21 1.20 1.15 1.14 1.14 1.13 1.01 0.99 0.96 0.95 0.94 0.93 0.92 0.91
4a
0.75 0.83 1.00 0.98 1.05 1.06 2.00 1.97 2.07 2.24 12.63 3.13
f1 (ppm)

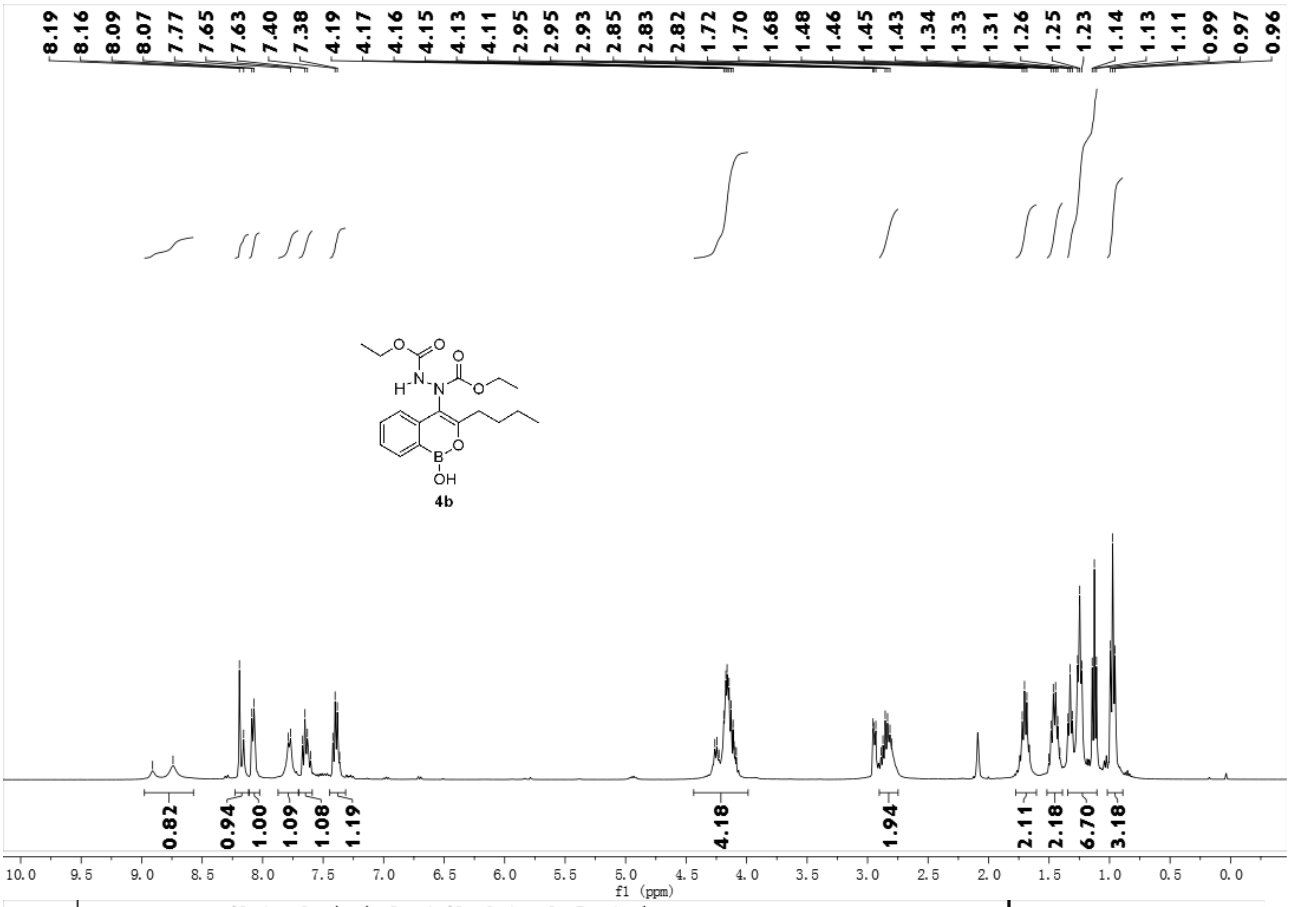

157.02 156.90 156.42 155.69 142.28 133.66 132.83 126.40 126.32 123.06 122.88 121.25 70.73 70.61 69.48 31.61 23.38 22.29 22.25 22.16 22.02 14.37 14.34
4a
f1 (ppm)

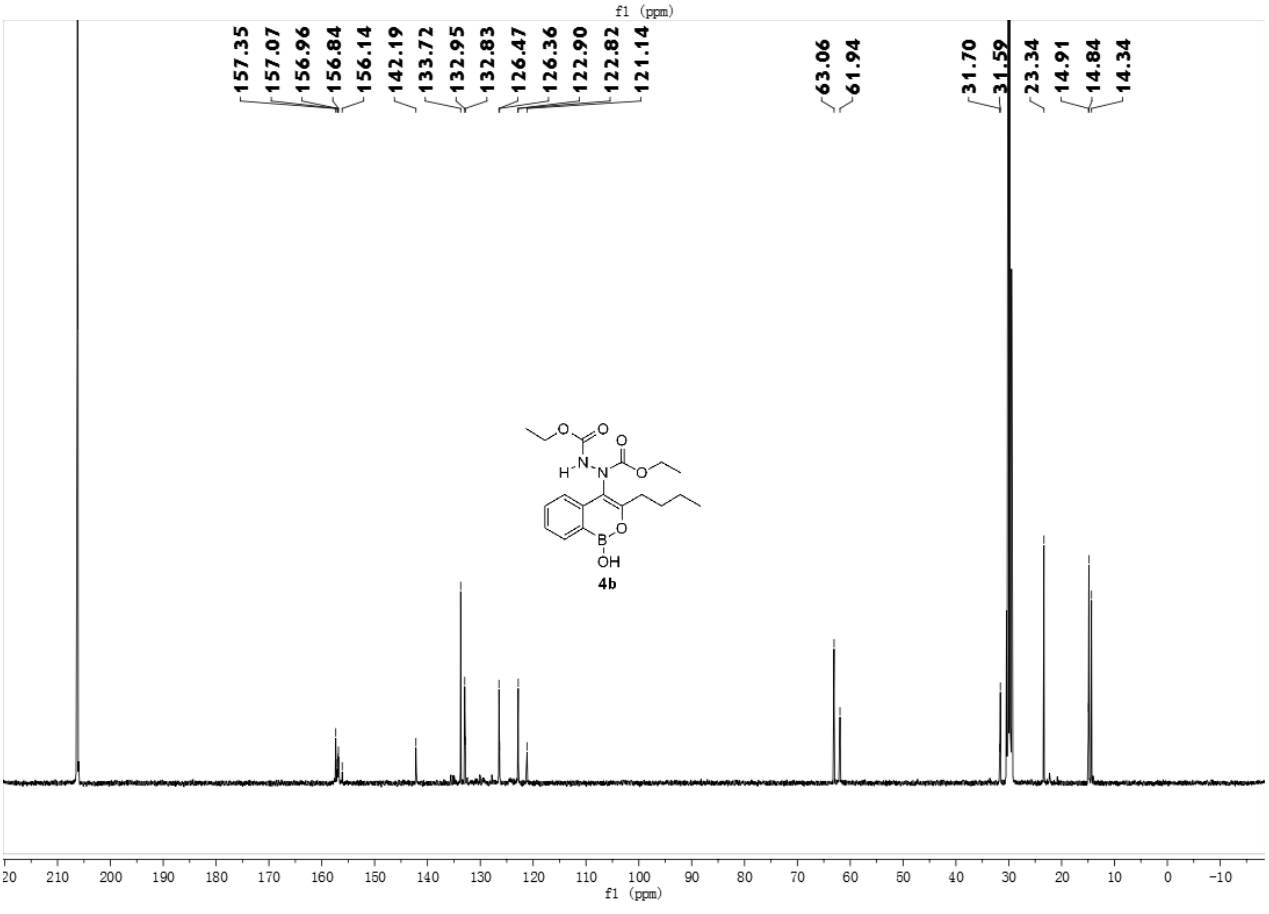

9.08 8.05 8.05 8.04 8.03 7.63 7.62 7.61 7.59 7.58 7.38 7.38 7.36 7.36 7.35 7.34 4.93 4.91 4.89 4.88 4.87 4.86 2.80 1.68 1.67 1.65 1.46 1.44 1.42 1.40 1.29 1.28 1.26 1.24 1.14 0.99 0.99 0.98 0.96 0.94
0.92 0.90 0.97 0.96 1.00 0.99 1.98 0.99 0.96 2.02 2.15 11.91 3.25
f1 (ppm)
4a
d6-DMSO, 70 °C

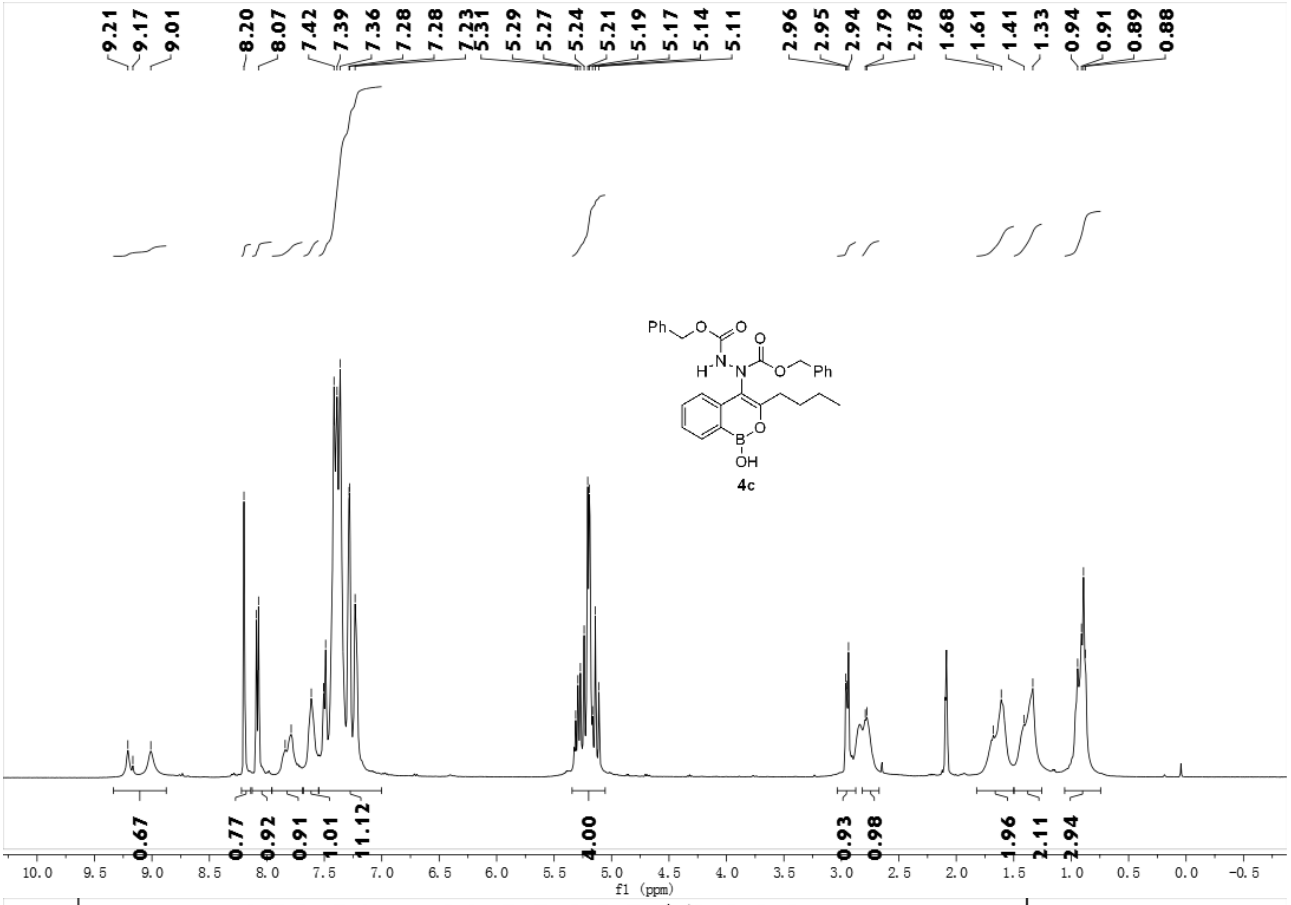

155.75 155.39 154.94 140.70 132.55 131.51 125.13 123.04 121.92 119.69
69.41 68.18
30.27 28.30 21.88 21.65 21.61 21.44 13.50
f1 (ppm)
4a
d6-DMSO, 70 °C

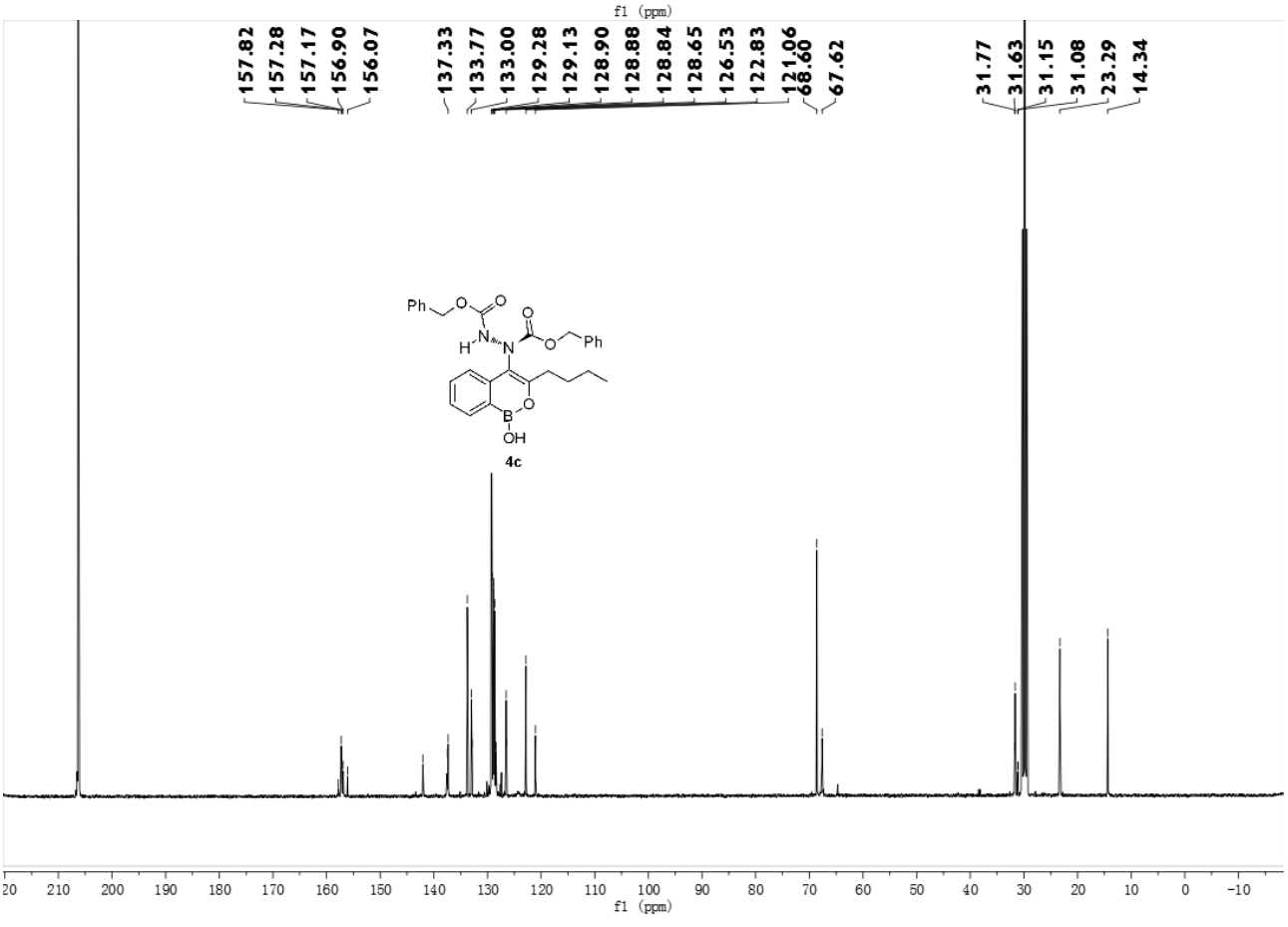

132.68
131.69
125.32
121.98
69.53
68.25
21.78
21.74
21.49
13.71
4a
d6-DMSO, 70°C
f1 (ppm)

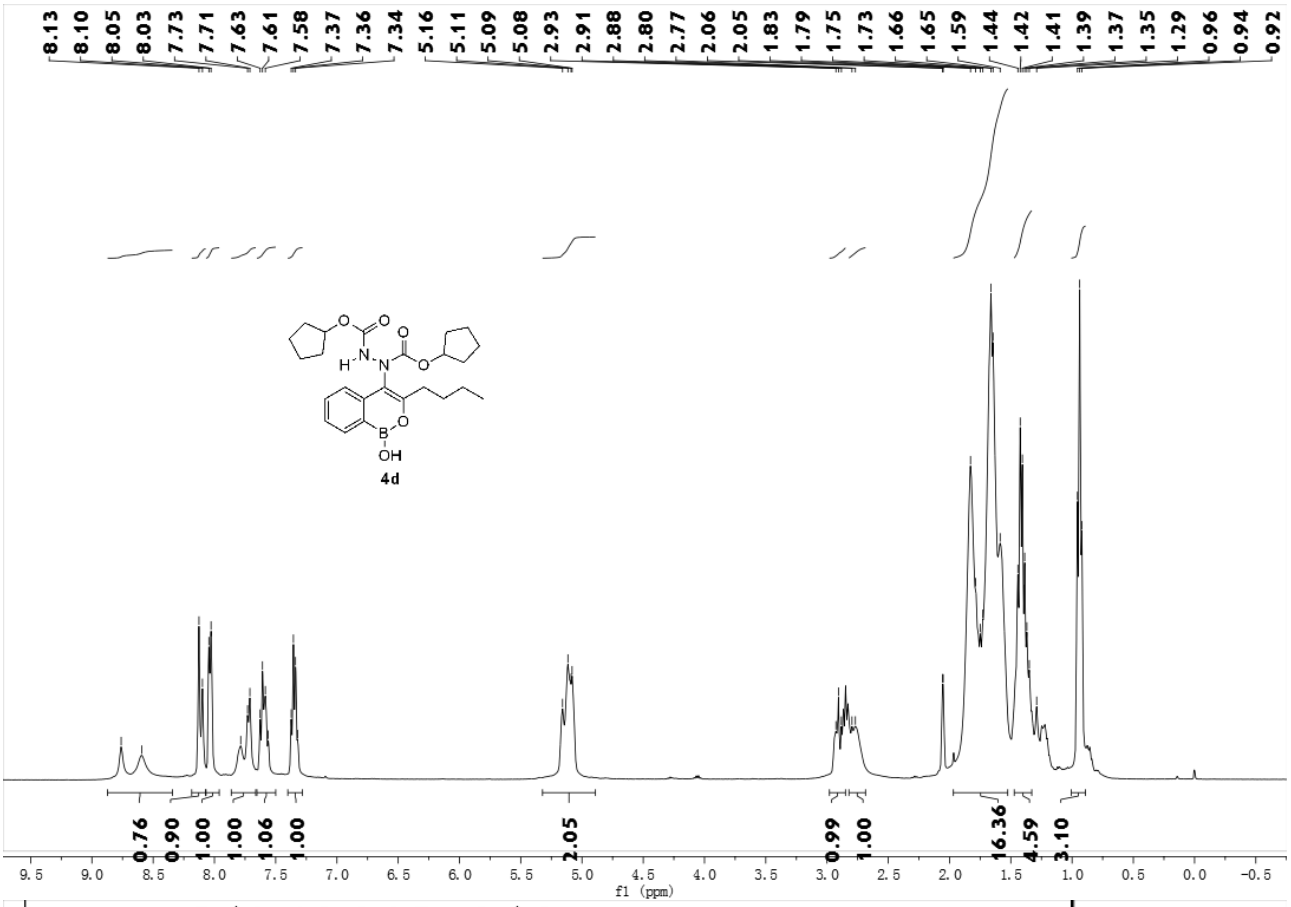

4a
d6-DMSO, 70°C
{0.79,13.87}
{1.65,14.35}
{0.94,22.51}
{1.25,68.83}
{2.79,120.32}
{8.02,123.89}
{8.03,132.07}
{8.03,141.22}
{7.58,141.33}
{4.89,155.98}
{1.65,155.97}
f2 (ppm)
f1 (ppm)

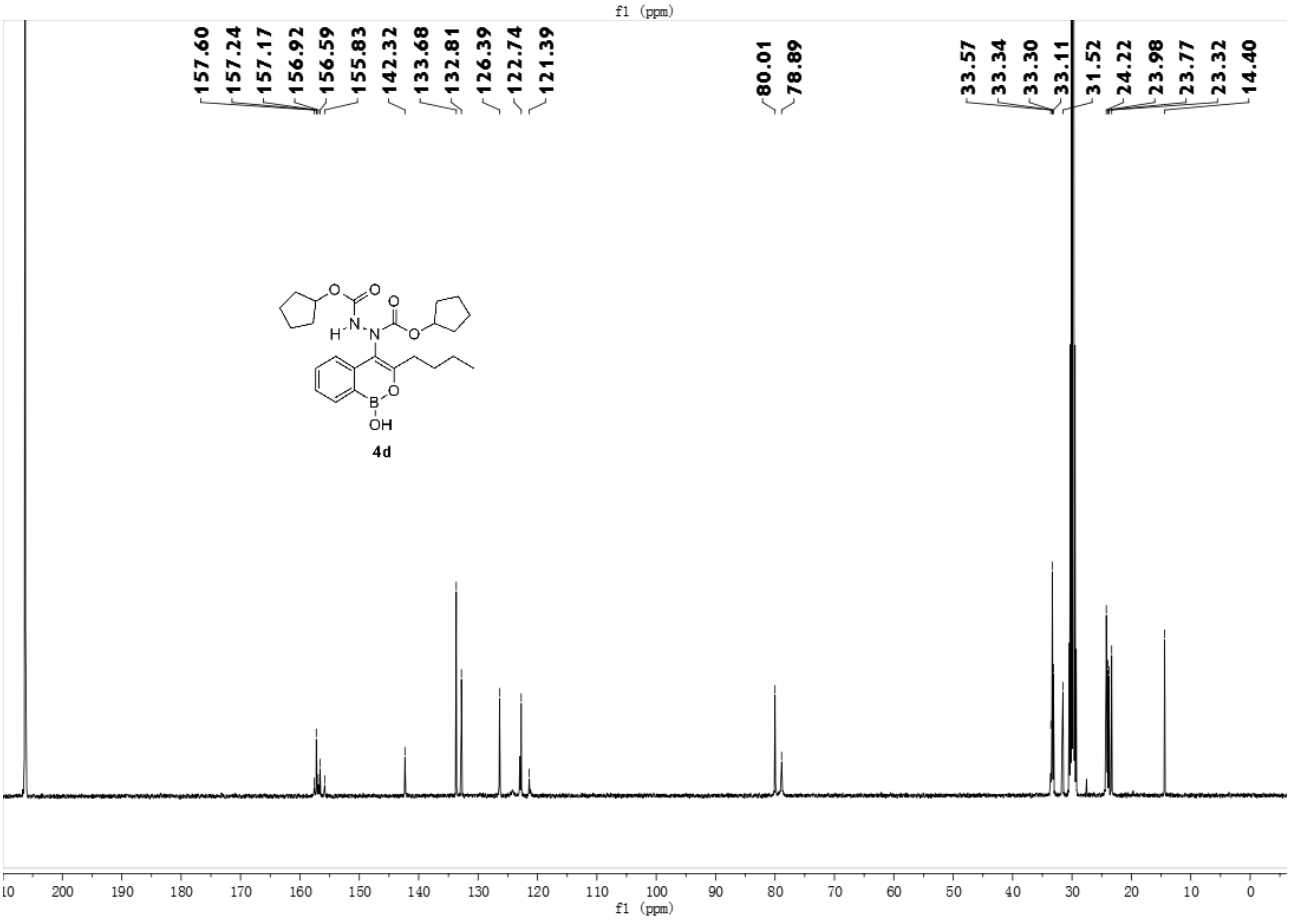

8.19
8.16
8.09
8.07
7.77
7.65
7.63
7.40
7.38
4.19
4.17
4.16
4.15
4.13
4.11
2.95
2.95
2.93
2.85
2.83
2.82
1.72
1.70
1.68
1.48
1.46
1.45
1.43
1.34
1.33
1.31
1.26
1.25
1.23
1.14
1.13
1.11
0.99
0.97
0.96
4b
0.82
0.94
1.00
1.09
1.08
1.19
4.18
1.94
2.11
2.18
6.70
3.18
f1 (ppm)

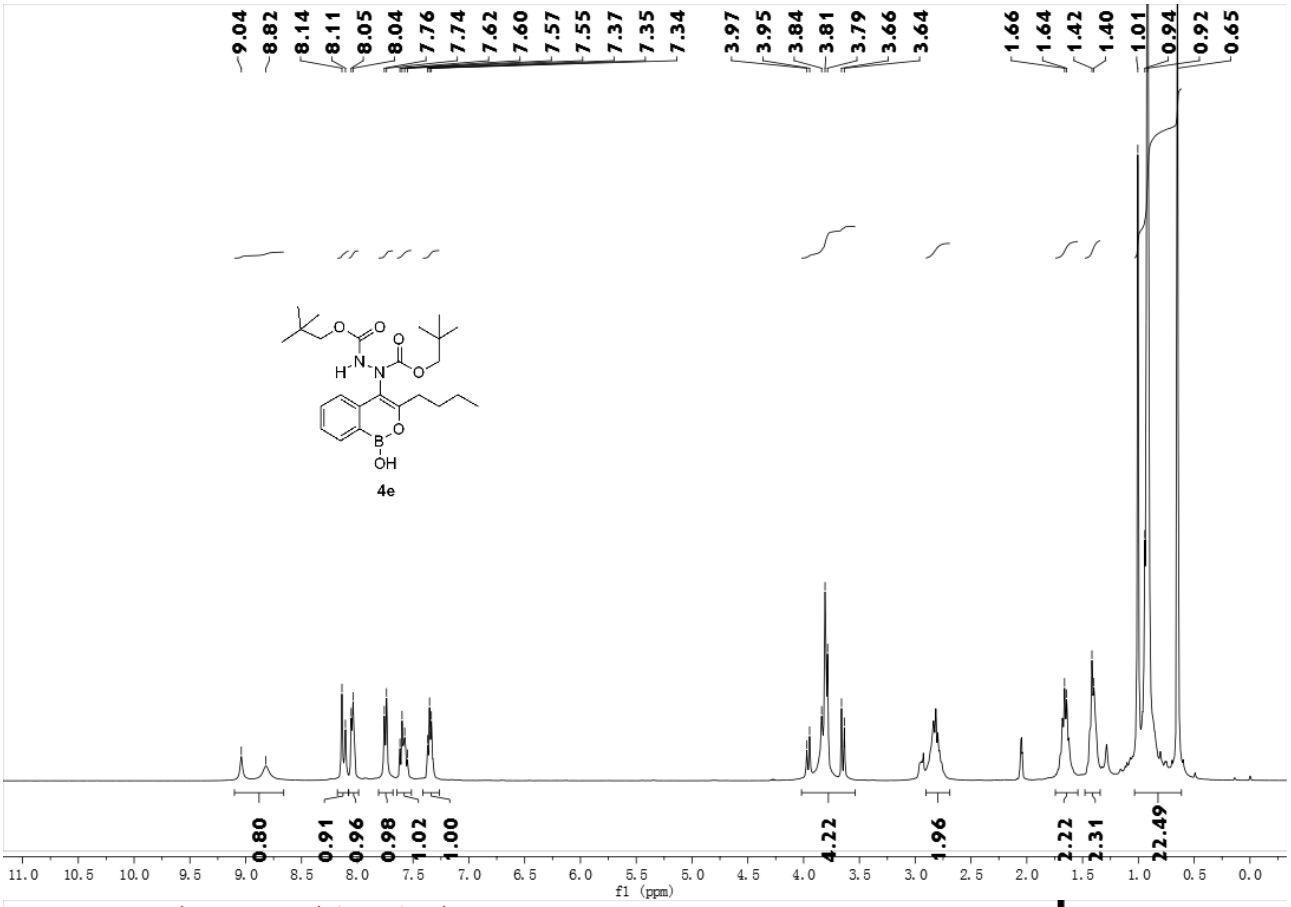

157.35
157.07
156.96
156.84
156.14
142.19
133.72
132.95
132.83
126.47
126.36
122.90
122.82
121.14
63.06
61.94
31.70
31.59
23.34
14.91
14.84
14.34
4b
f1 (ppm)

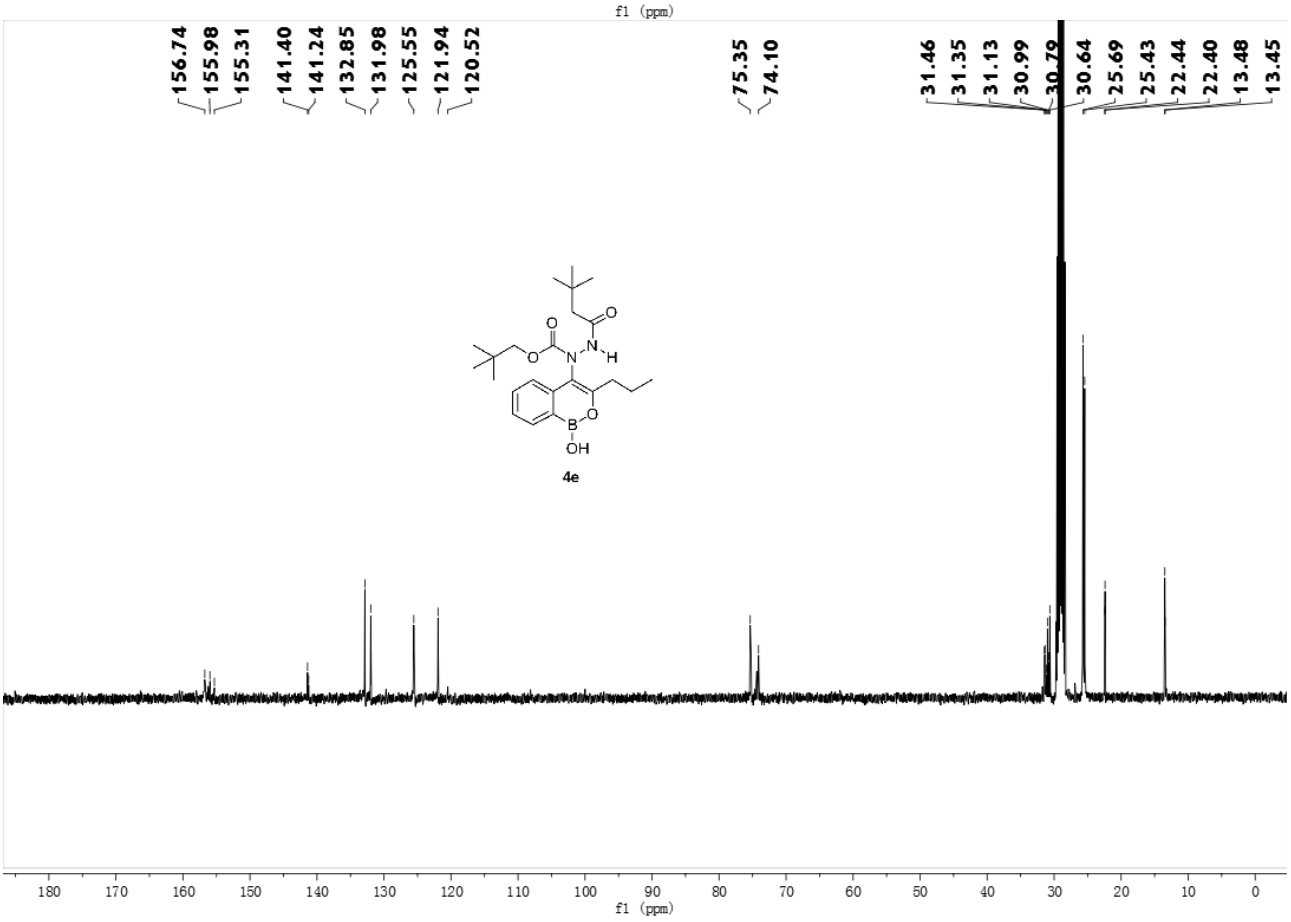

9.21
9.17
9.01
8.20
8.07
7.42
7.39
7.36
7.28
7.28
7.23
5.31
5.29
5.27
5.24
5.21
5.19
5.17
5.14
5.11
2.96
2.95
2.94
2.79
2.78
1.68
1.61
1.41
1.33
0.94
0.91
0.89
0.88
Ph
O
O
H
N
N
O
O
Ph
B
O
OH
4c
0.67
0.77
0.92
0.91
1.01
11.12
4.00
0.93
0.98
1.96
2.11
2.94
f1 (ppm)

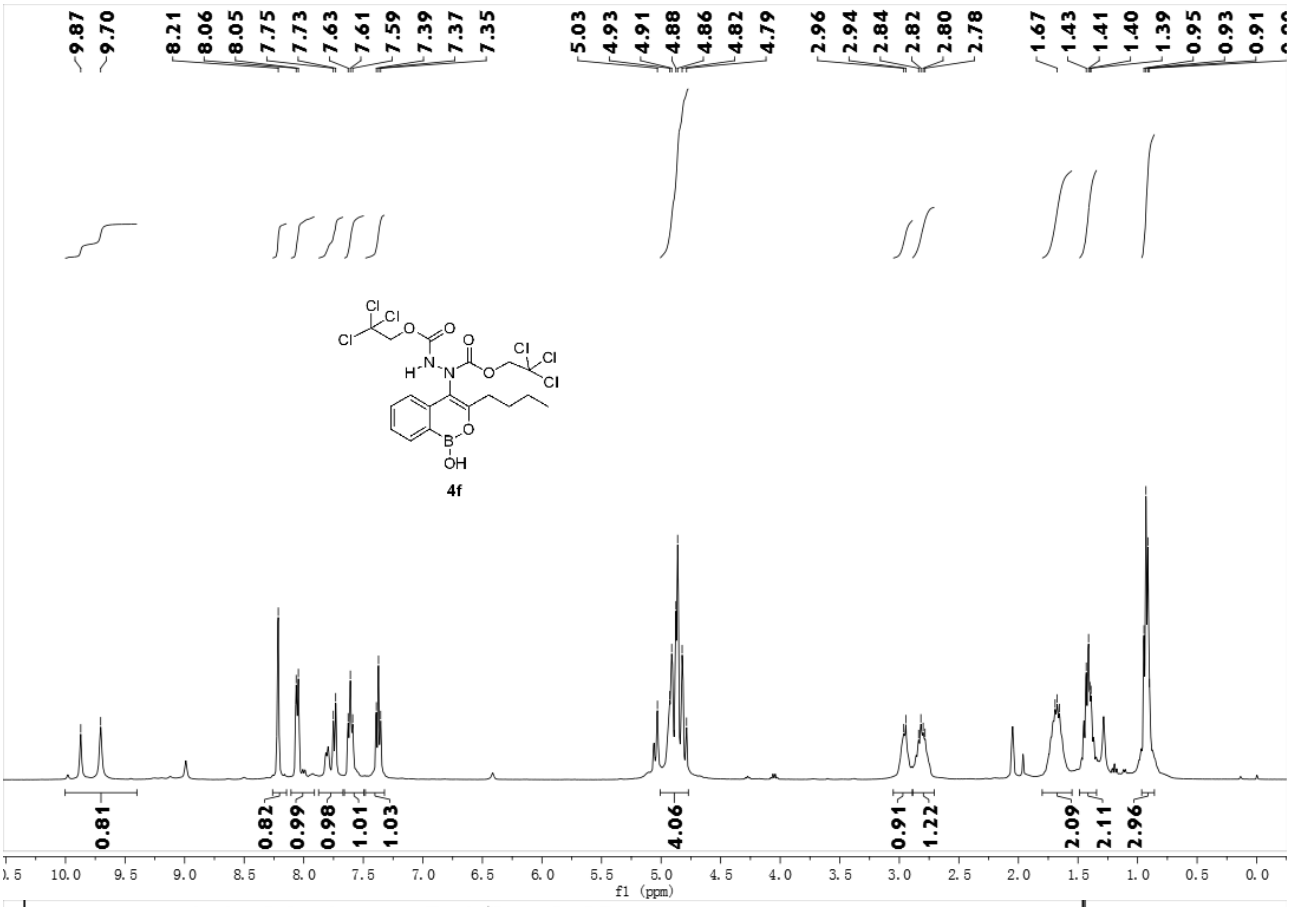

157.82
157.28
157.17
156.90
156.07
137.33
133.77
133.00
129.28
129.13
128.90
128.88
128.84
128.65
126.53
122.83
121.06
68.60
67.62
31.77
31.63
31.15
31.08
23.29
14.34
Ph
O
O
H
N
N
O
O
Ph
B
O
OH
4c
f1 (ppm)


8.13
8.10
8.05
8.03
7.73
7.71
7.63
7.61
7.58
7.37
7.36
7.34
5.16
5.11
5.09
5.08
2.93
2.91
2.88
2.80
2.77
2.06
2.05
1.83
1.79
1.75
1.73
1.66
1.65
1.59
1.44
1.42
1.41
1.39
1.37
1.35
1.29
0.96
0.94
0.92
4d
0.76
0.90
1.00
1.00
1.06
1.00
2.05
0.99
1.00
16.36
4.59
3.10
f1 (ppm)

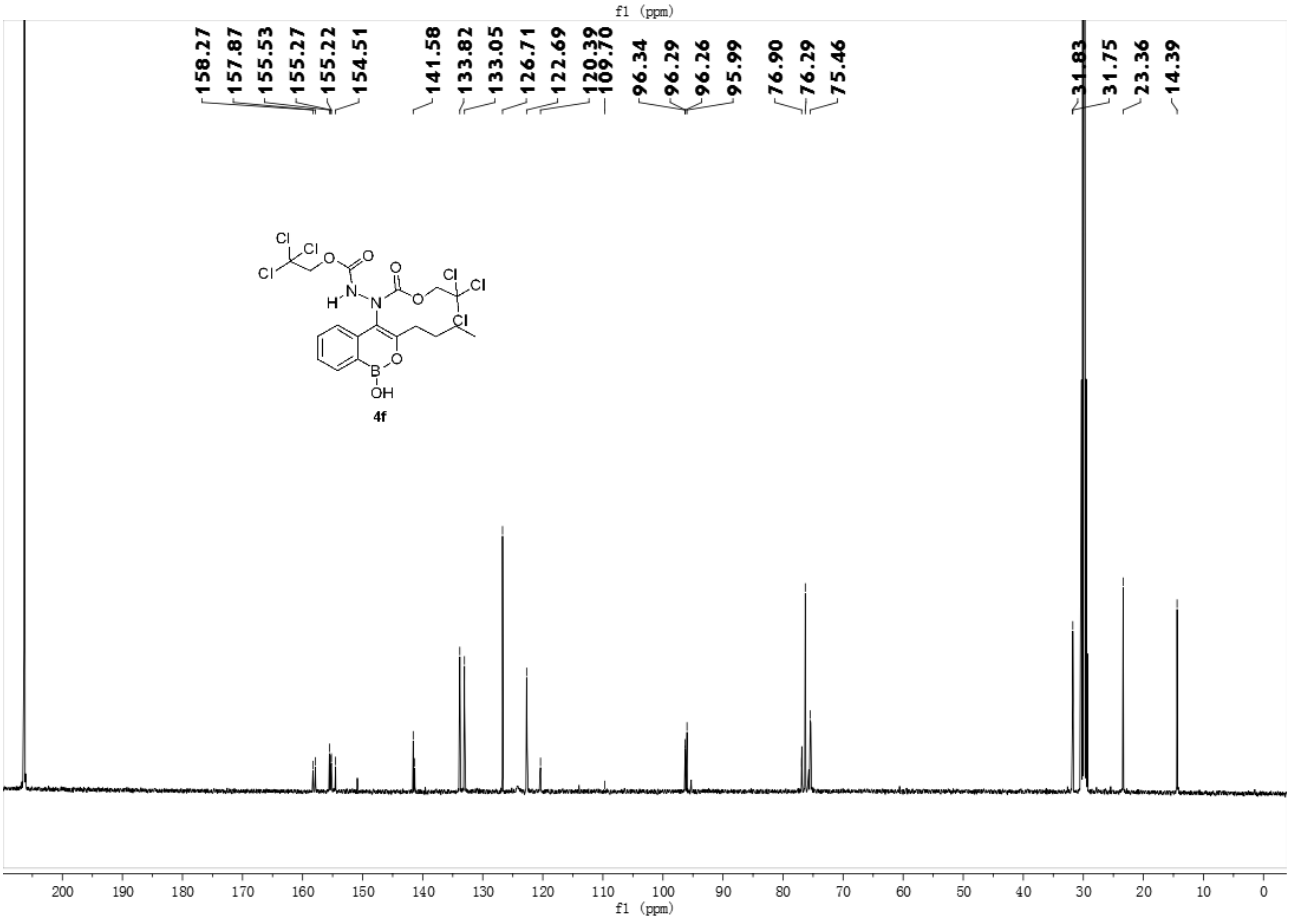

157.60
157.24
157.17
156.92
156.59
155.83
142.32
133.68
132.81
126.39
122.74
121.39
80.01
78.89
33.57
33.34
33.30
33.11
31.52
24.22
23.98
23.77
23.32
14.40
4d
f1 (ppm)


9.04
8.82
8.14
8.11
8.05
8.04
7.76
7.74
7.62
7.60
7.57
7.55
7.37
7.35
7.34
3.97
3.95
3.84
3.81
3.79
3.66
3.64
1.66
1.64
1.42
1.40
1.01
0.94
0.92
0.65
4e
0.80
0.91
0.96
0.98
1.02
1.00
4.22
1.96
2.22
2.31
22.49
f1 (ppm)

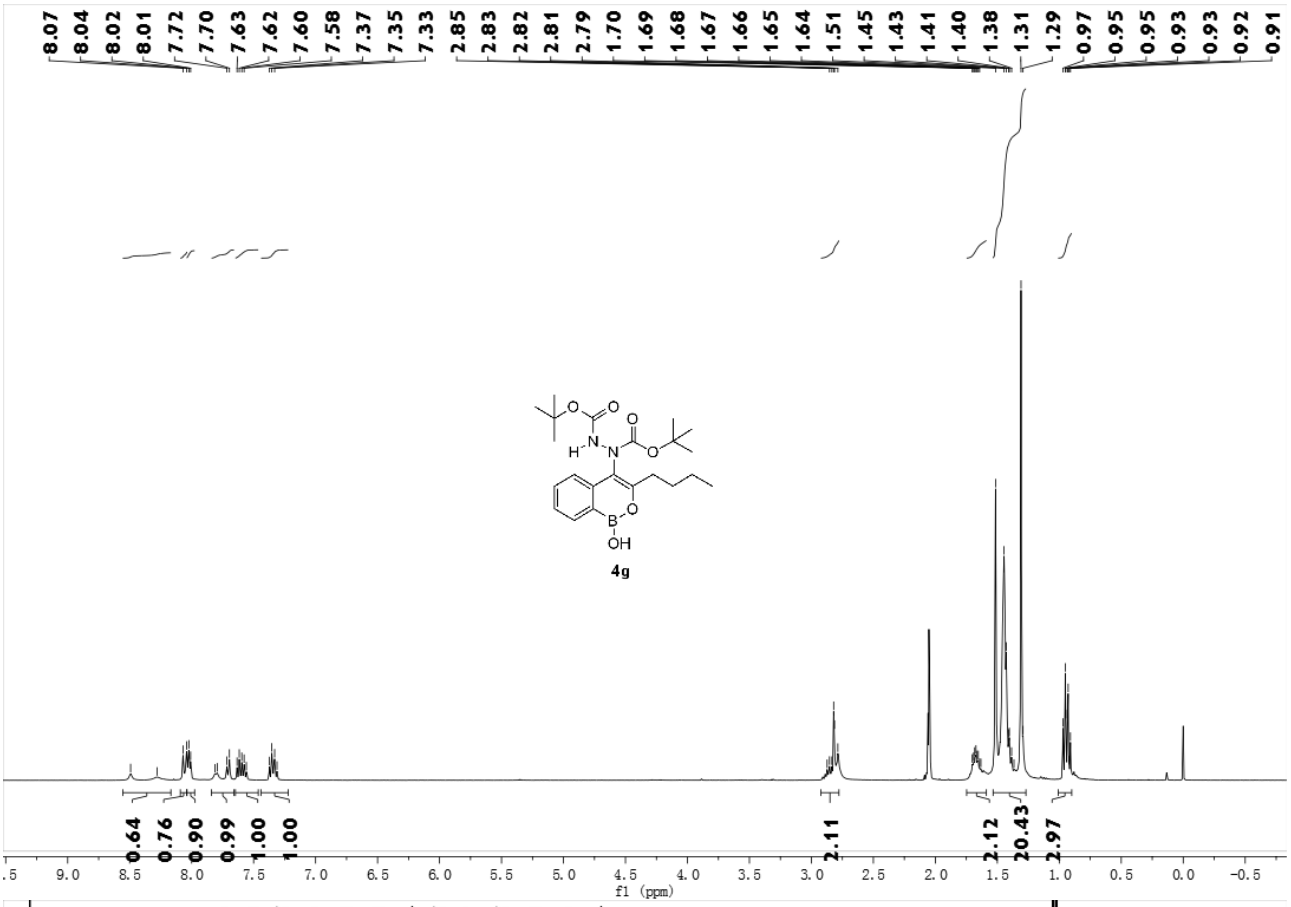

156.74
155.98
155.31
141.40
141.24
132.85
131.98
125.55
121.94
120.52
75.35
74.10
31.46
31.35
31.13
30.99
30.79
30.64
25.69
25.43
22.44
22.40
13.48
13.45
4e
f1 (ppm)


9.87
9.70
8.21
8.06
8.05
7.75
7.73
7.63
7.61
7.59
7.39
7.37
7.35
5.03
4.93
4.91
4.88
4.86
4.82
4.79
2.96
2.94
2.84
2.82
2.80
2.78
1.67
1.43
1.41
1.40
1.39
0.95
0.93
0.91
0.81
0.82
0.99
0.98
1.01
1.03
4.06
0.91
1.22
2.09
2.11
2.96
f1 (ppm)

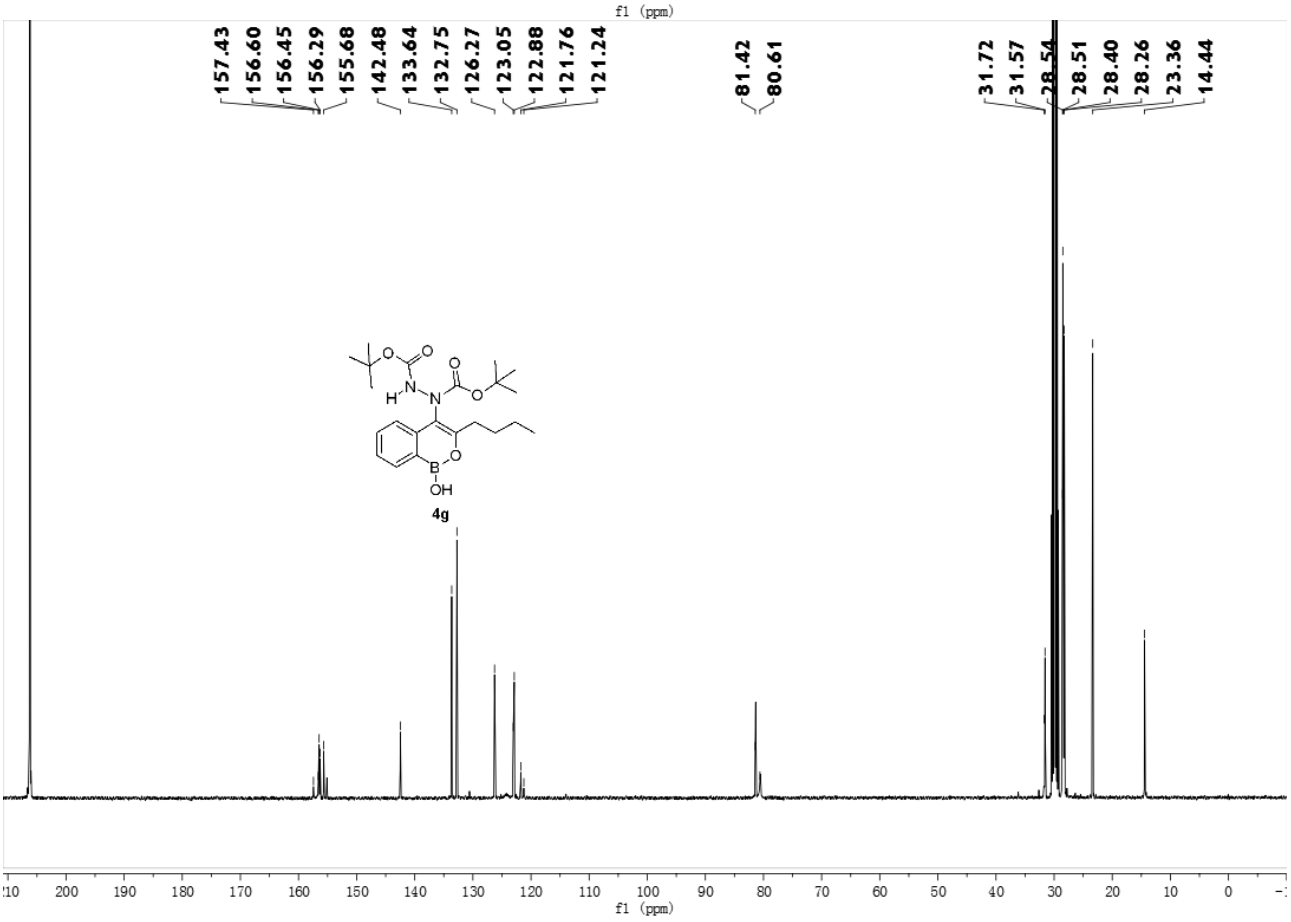
4f


158.27
157.87
155.53
155.27
155.22
154.51
141.58
133.82
133.05
126.71
122.69
120.39
109.70
96.34
96.29
96.26
95.99
76.90
76.29
75.46
31.83
31.75
23.36
14.39
f1 (ppm)

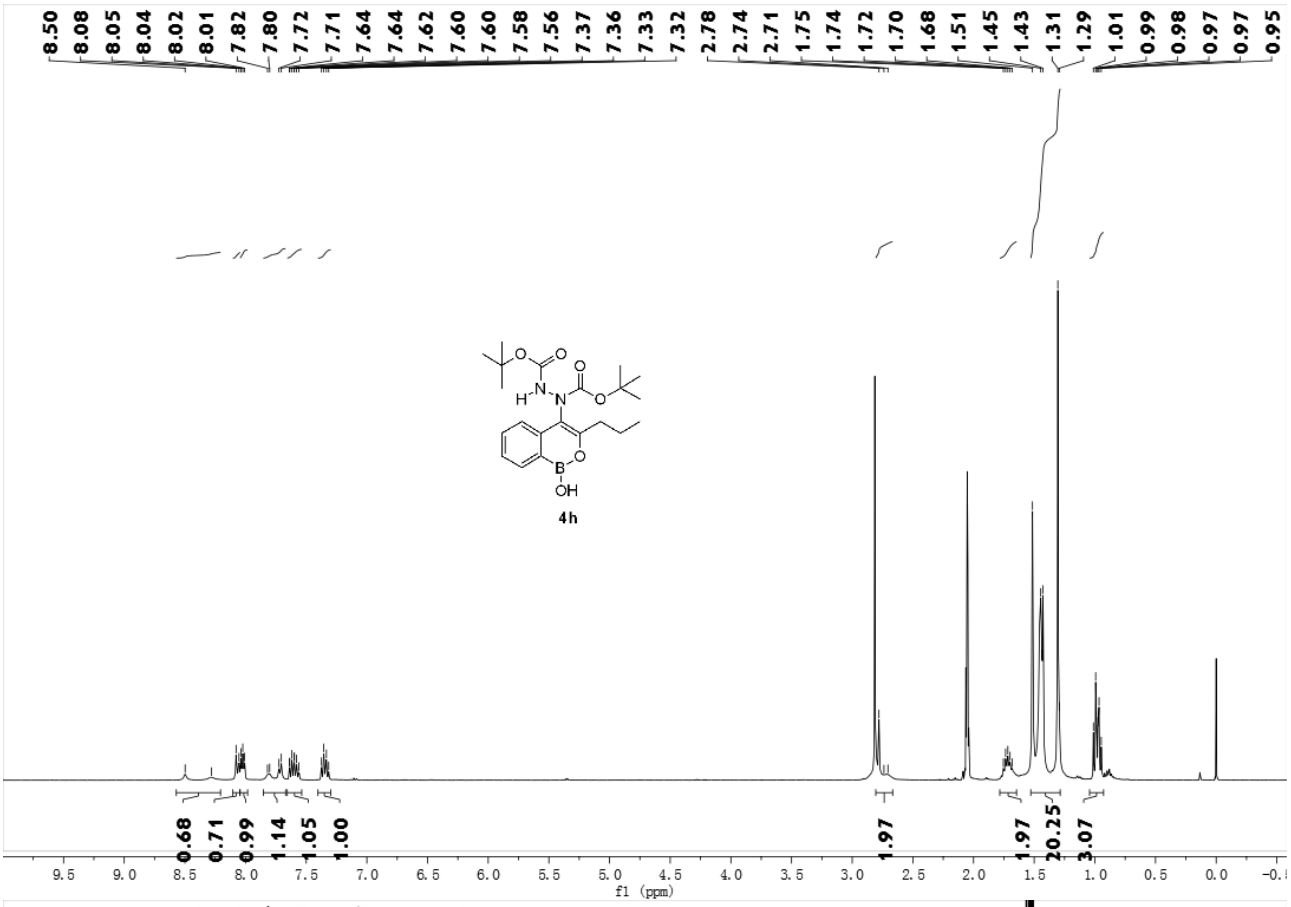
4f


8.07 8.04 8.02 8.01 7.72 7.70 7.63 7.62 7.60 7.58 7.37 7.35 7.33
2.85 2.83 2.82 2.81 2.79 1.70 1.69 1.68 1.67 1.66 1.65 1.64 1.51 1.45 1.43 1.41 1.40 1.38 1.31 1.29
0.97 0.95 0.95 0.93 0.93 0.92 0.91
0.64 0.76 0.90 0.99 1.00 1.00 2.11 2.12 20.43 2.97
f1 (ppm)

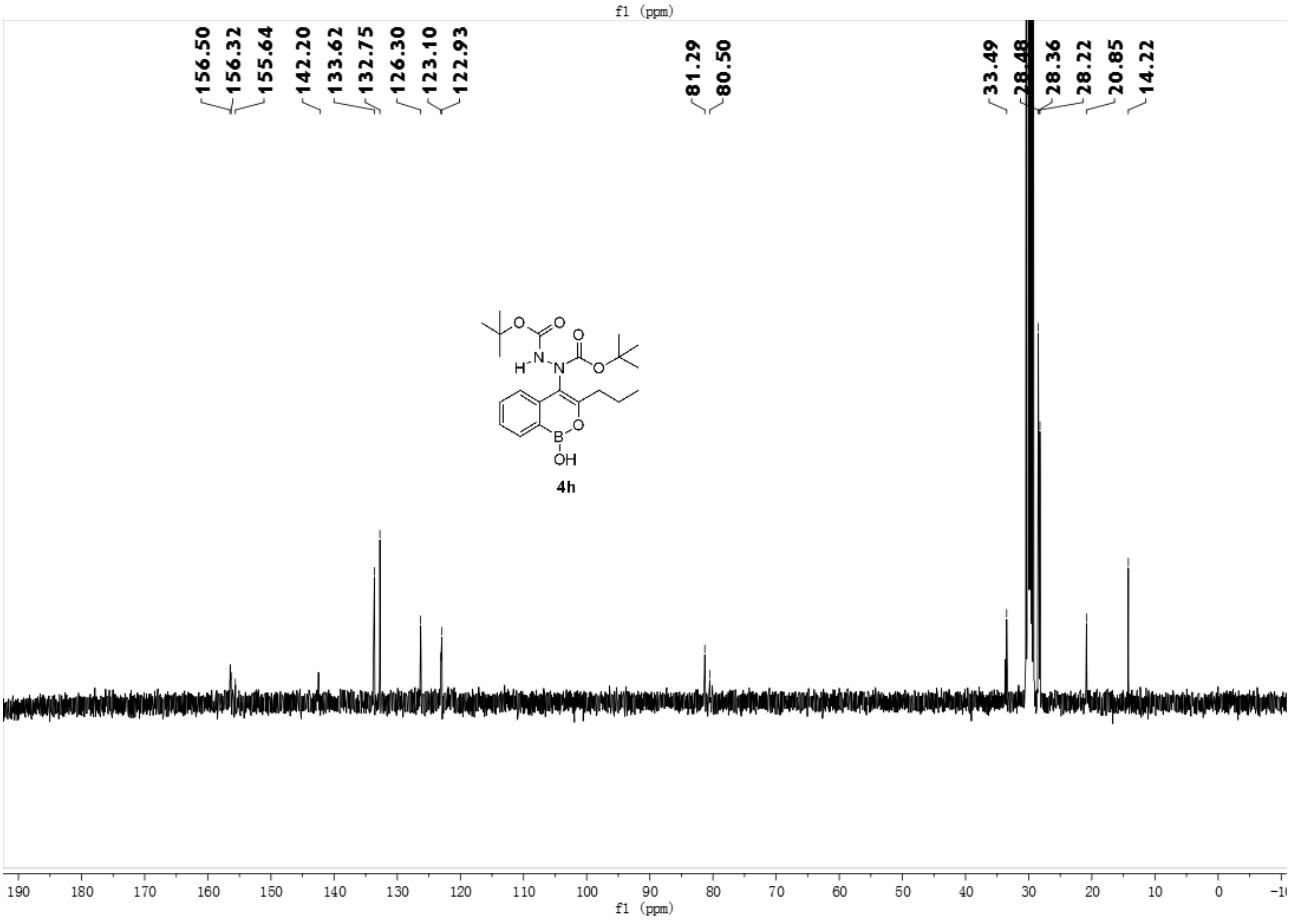
4g


157.43 156.60 156.45 156.29 155.68 142.48 133.64 132.75 126.27 123.05 122.88 121.76 121.24
81.42 80.61
31.72 31.57 28.54 28.51 28.40 28.26 23.36 14.44
f1 (ppm)

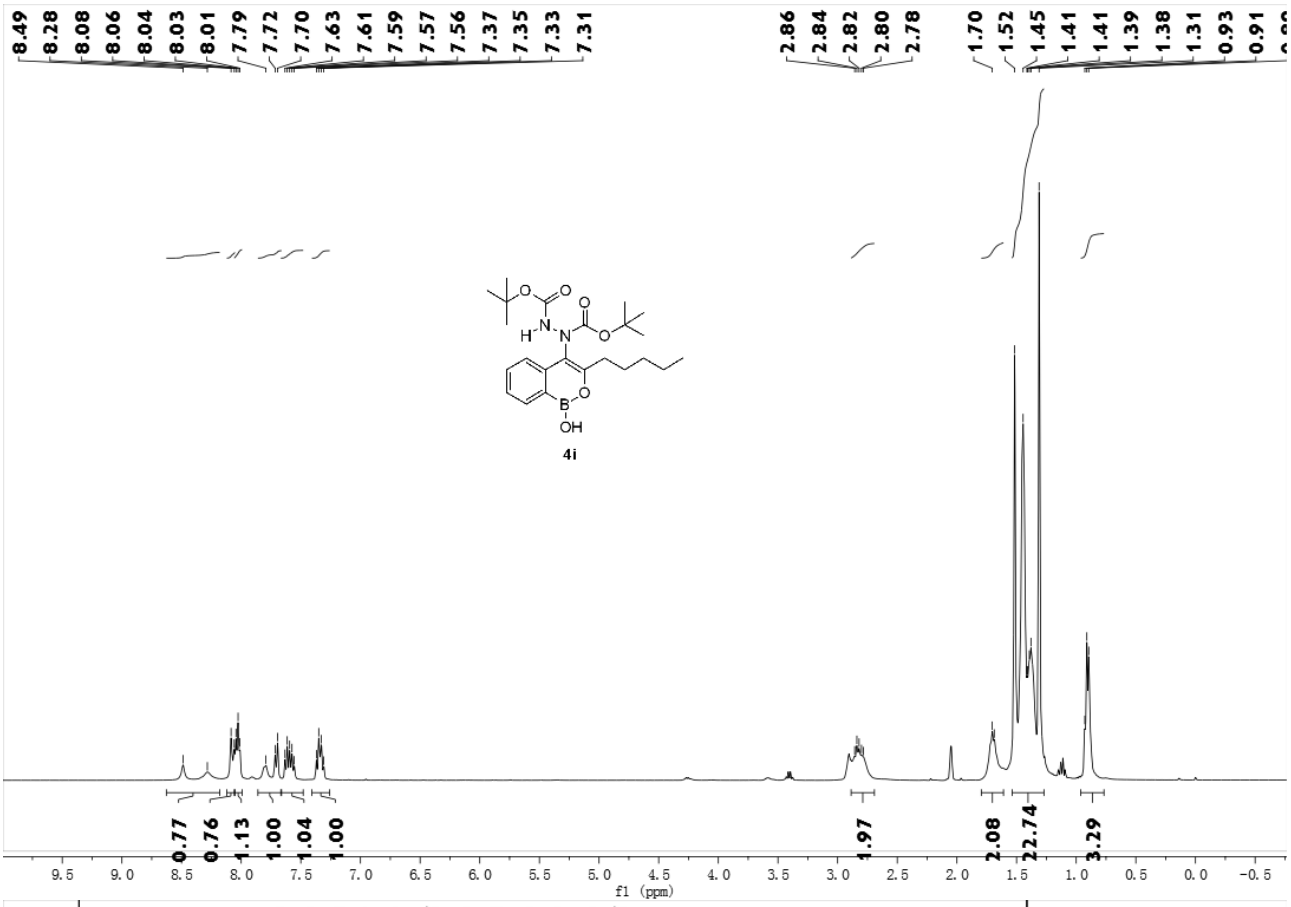
4g

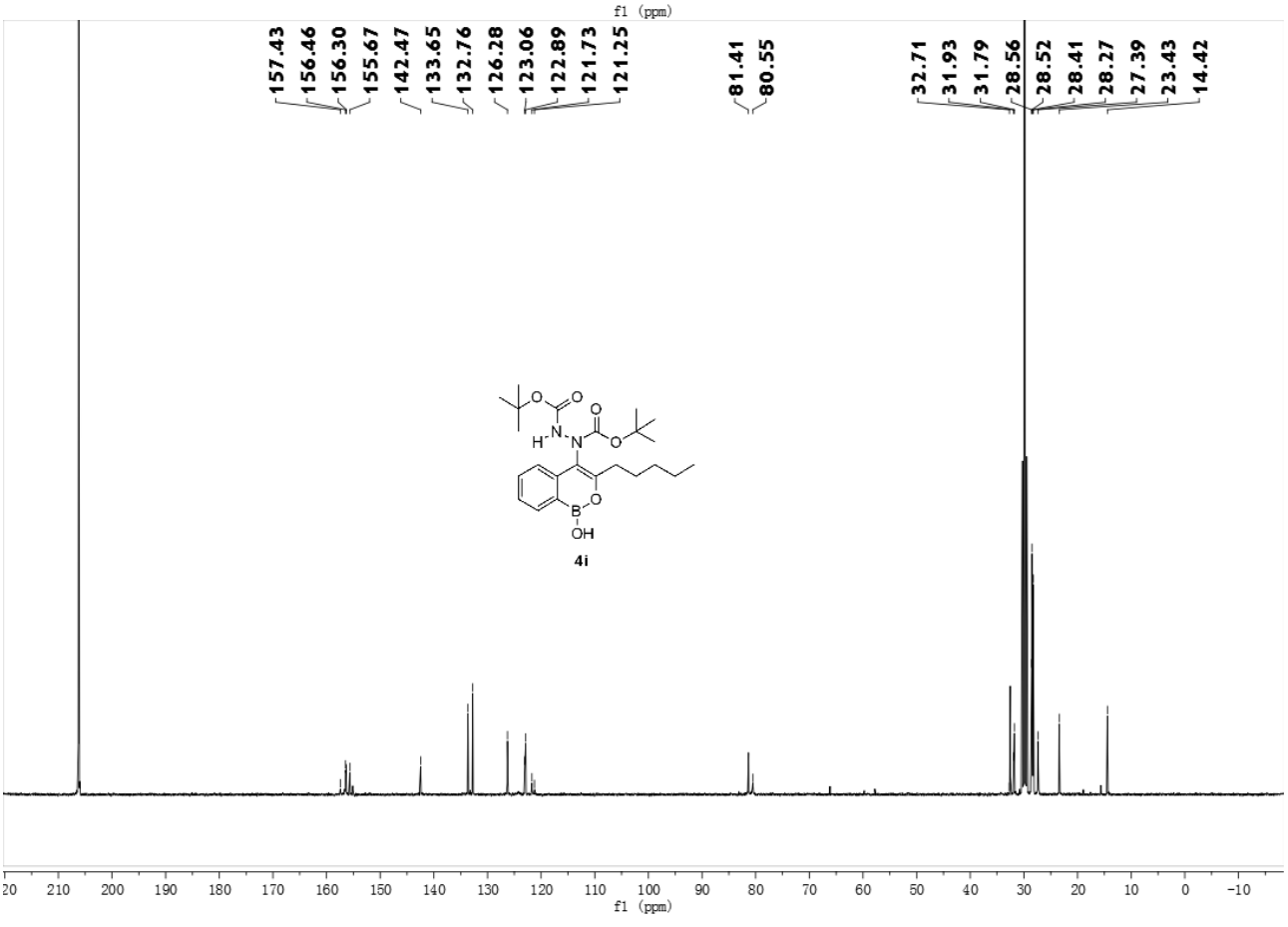

8.50 8.08 8.05 8.04 8.02 8.01 7.82 7.80 7.72 7.71 7.64 7.64 7.62 7.60 7.60 7.58 7.56 7.37 7.36 7.33 7.32
2.78 2.74 2.71 1.75 1.74 1.72 1.70 1.68 1.51 1.45 1.43 1.31 1.29 1.01 0.99 0.98 0.97 0.97 0.95
0.68 0.71 0.99 1.14 1.05 1.00
1.97 1.97 20.25 3.07
f1 (ppm)

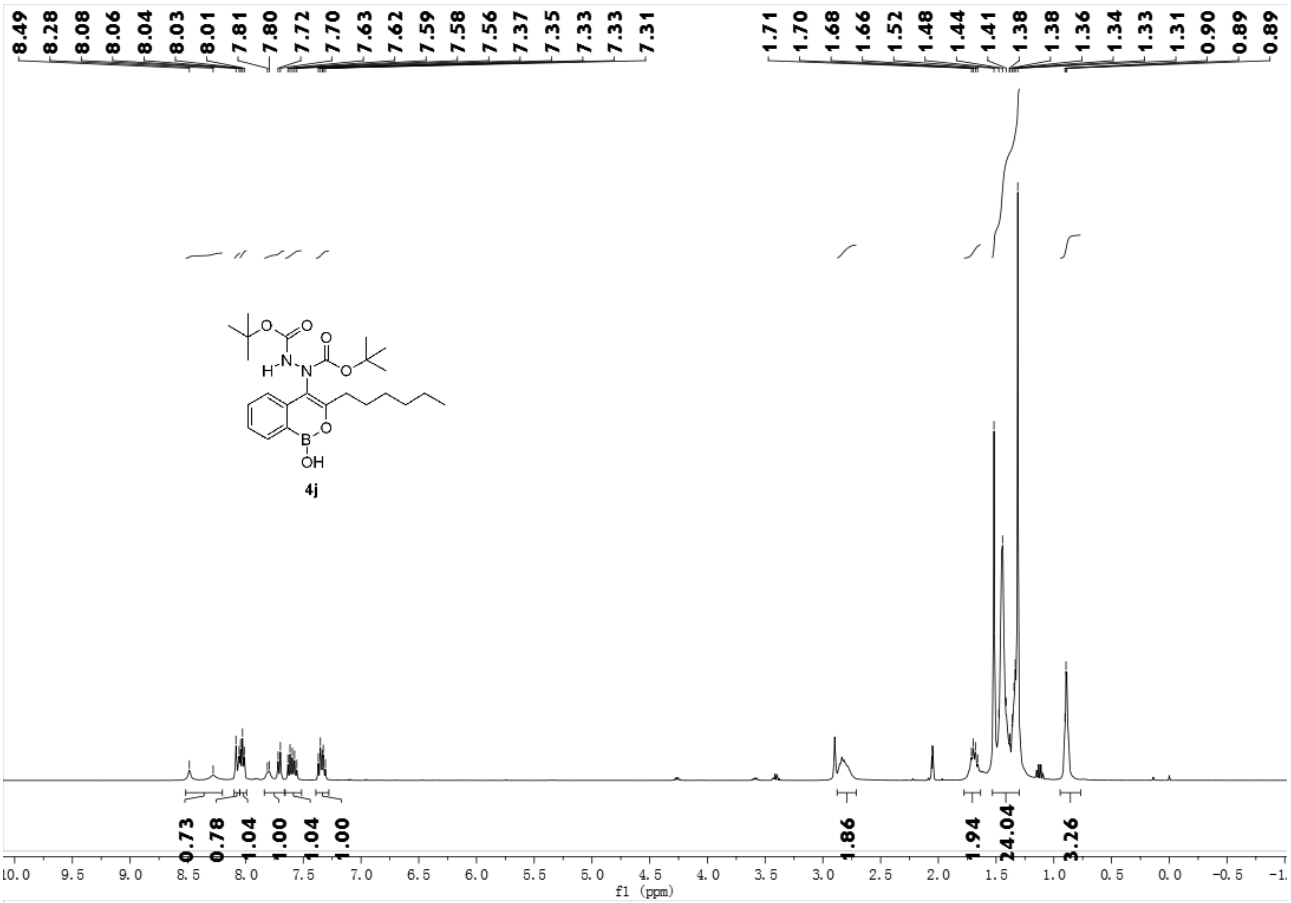
4h

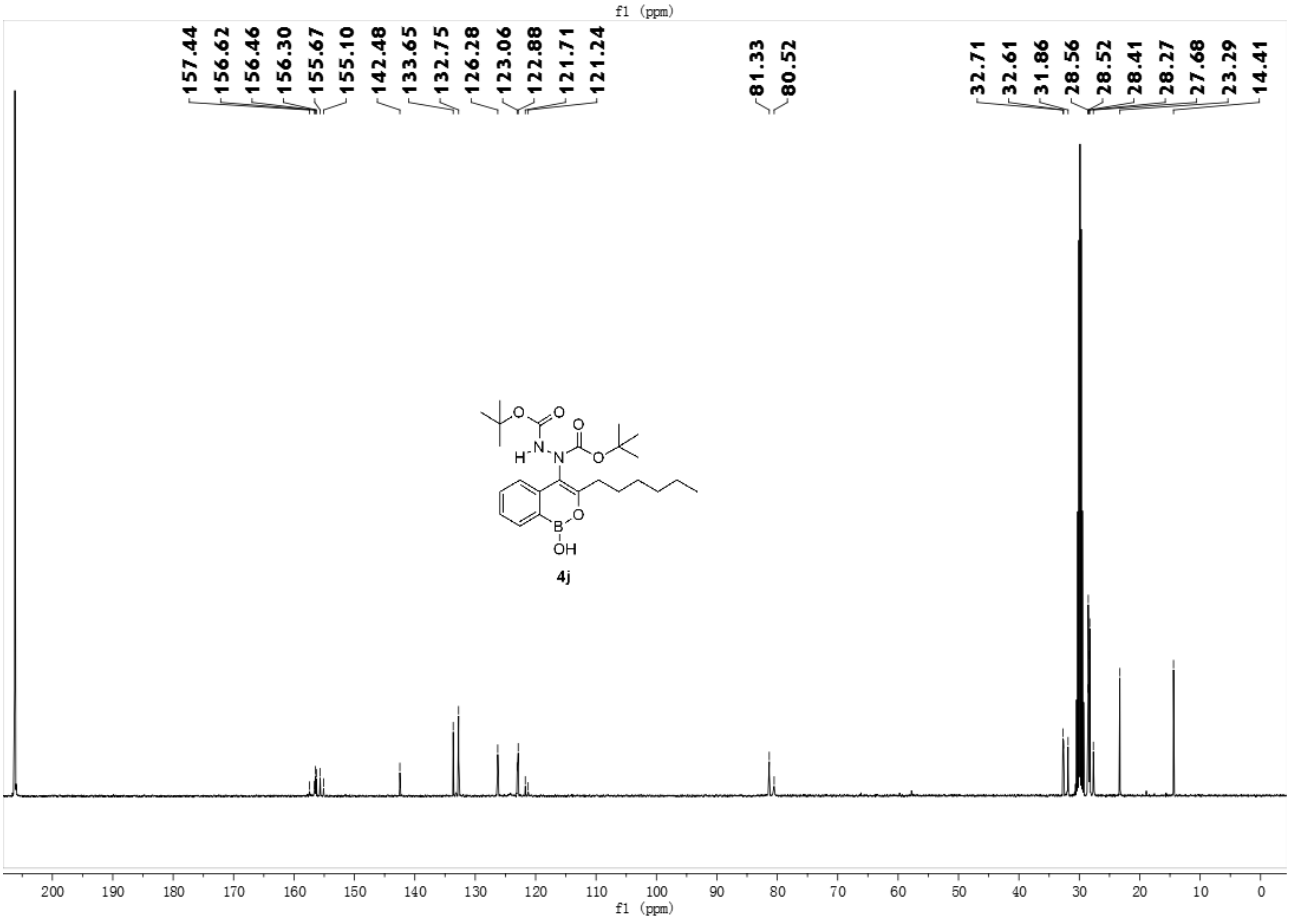

156.50 156.32 155.64 142.20 133.62 132.75 126.30 123.10 122.93
81.29 80.50
33.49 28.48 28.36 28.22 20.85 14.22
f1 (ppm)

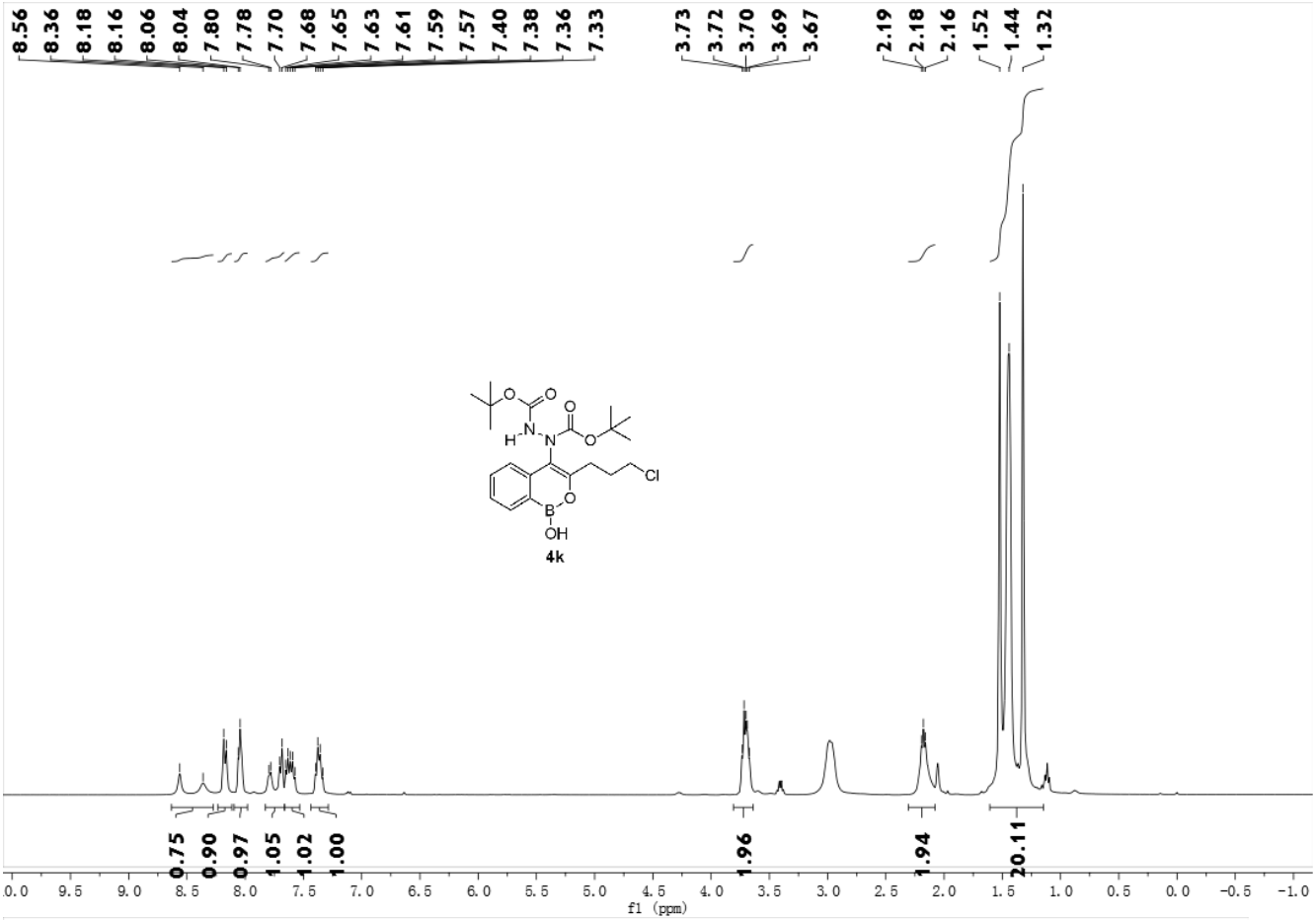
4h

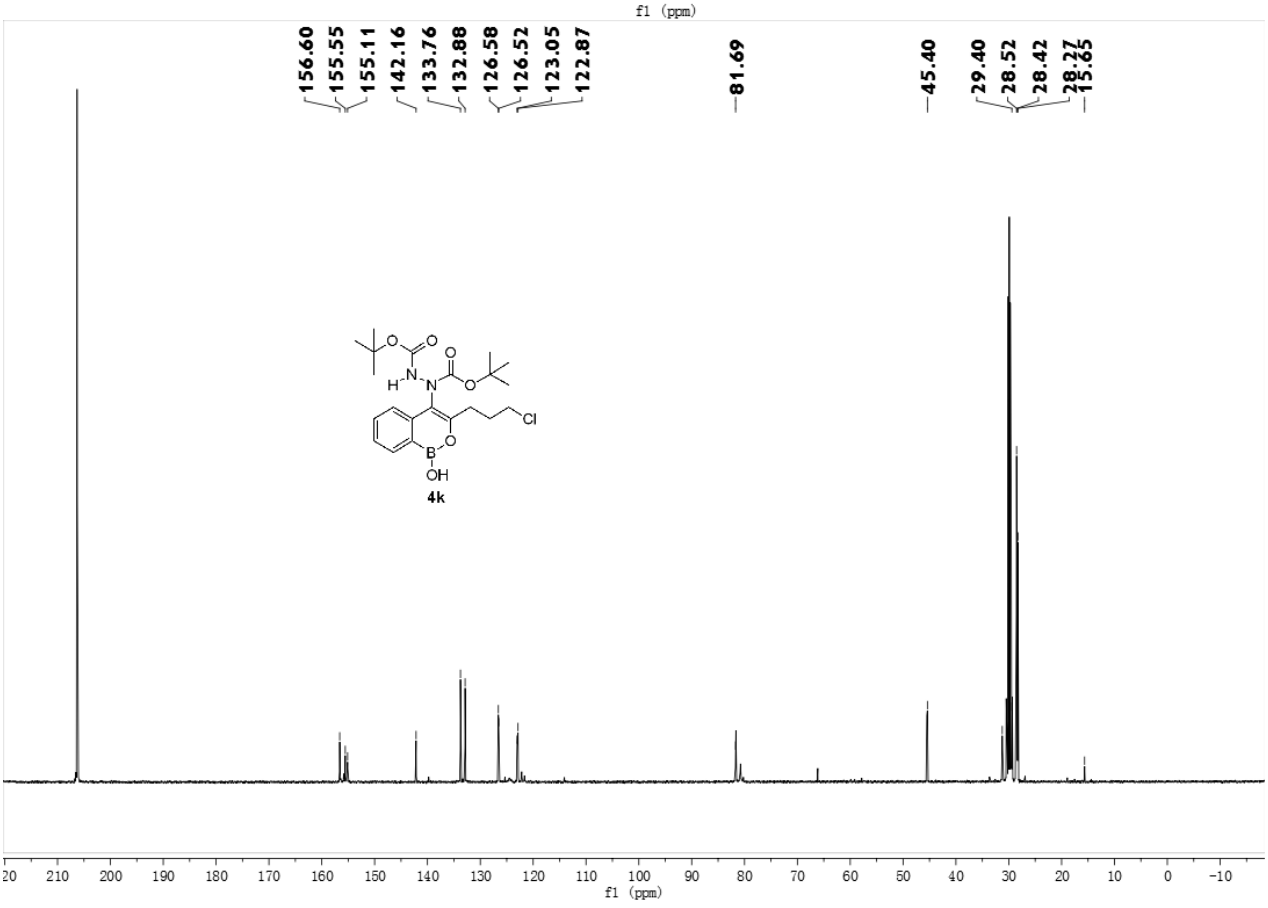

8.49
8.28
8.08
8.06
8.04
8.03
8.01
7.79
7.72
7.70
7.63
7.61
7.59
7.57
7.56
7.37
7.35
7.33
7.31
2.86
2.84
2.82
2.80
2.78
1.70
1.52
1.45
1.41
1.41
1.39
1.38
1.31
0.93
0.91
0.77
0.76
1.13
1.00
1.04
1.00
1.97
2.08
22.74
3.29
f1 (ppm)
4i

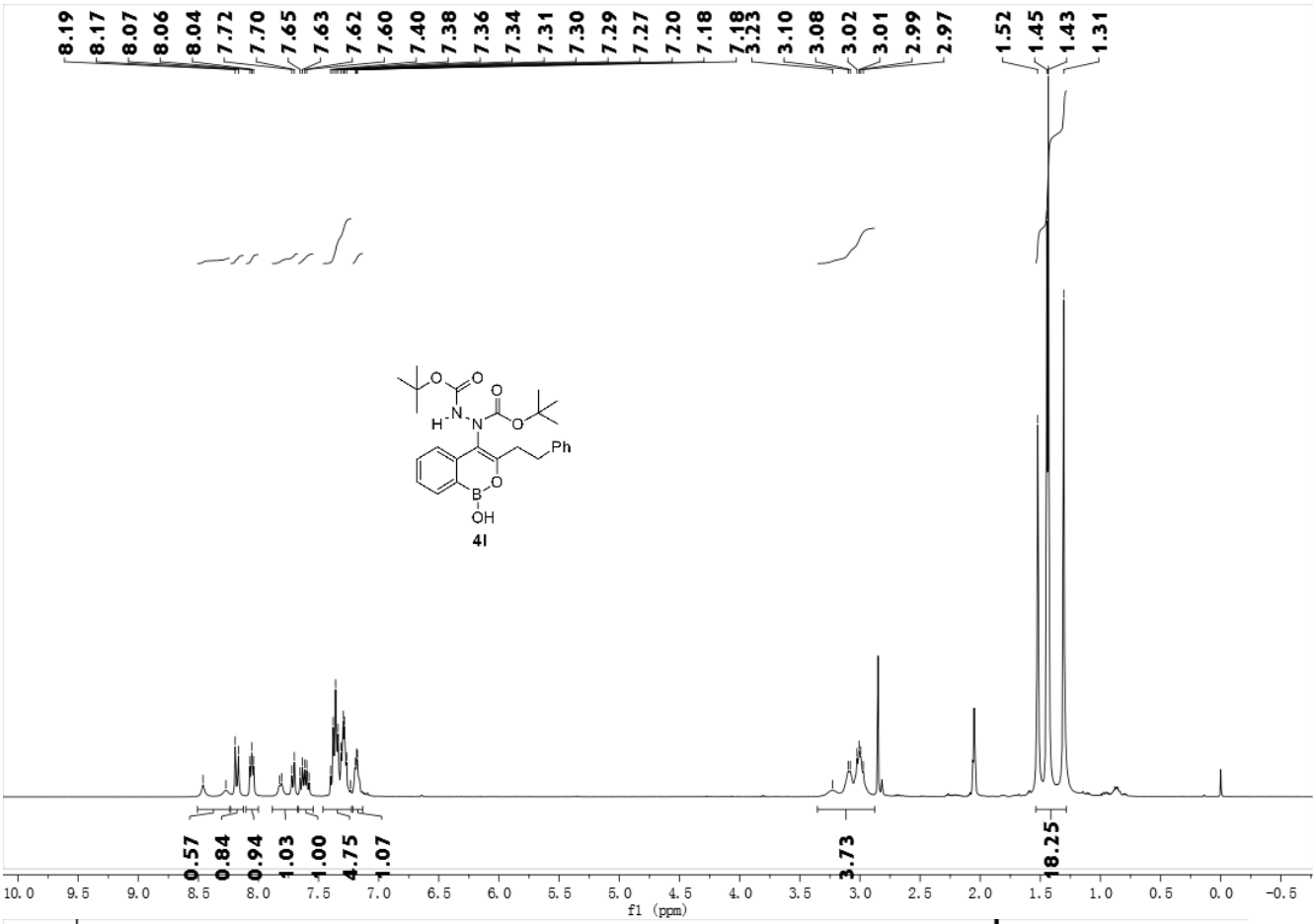

157.43
156.46
156.30
155.67
142.47
133.65
132.76
126.28
123.06
122.89
121.73
121.25
81.41
80.55
32.71
31.93
31.79
28.56
28.52
28.41
28.27
27.39
23.43
14.42
f1 (ppm)
4i

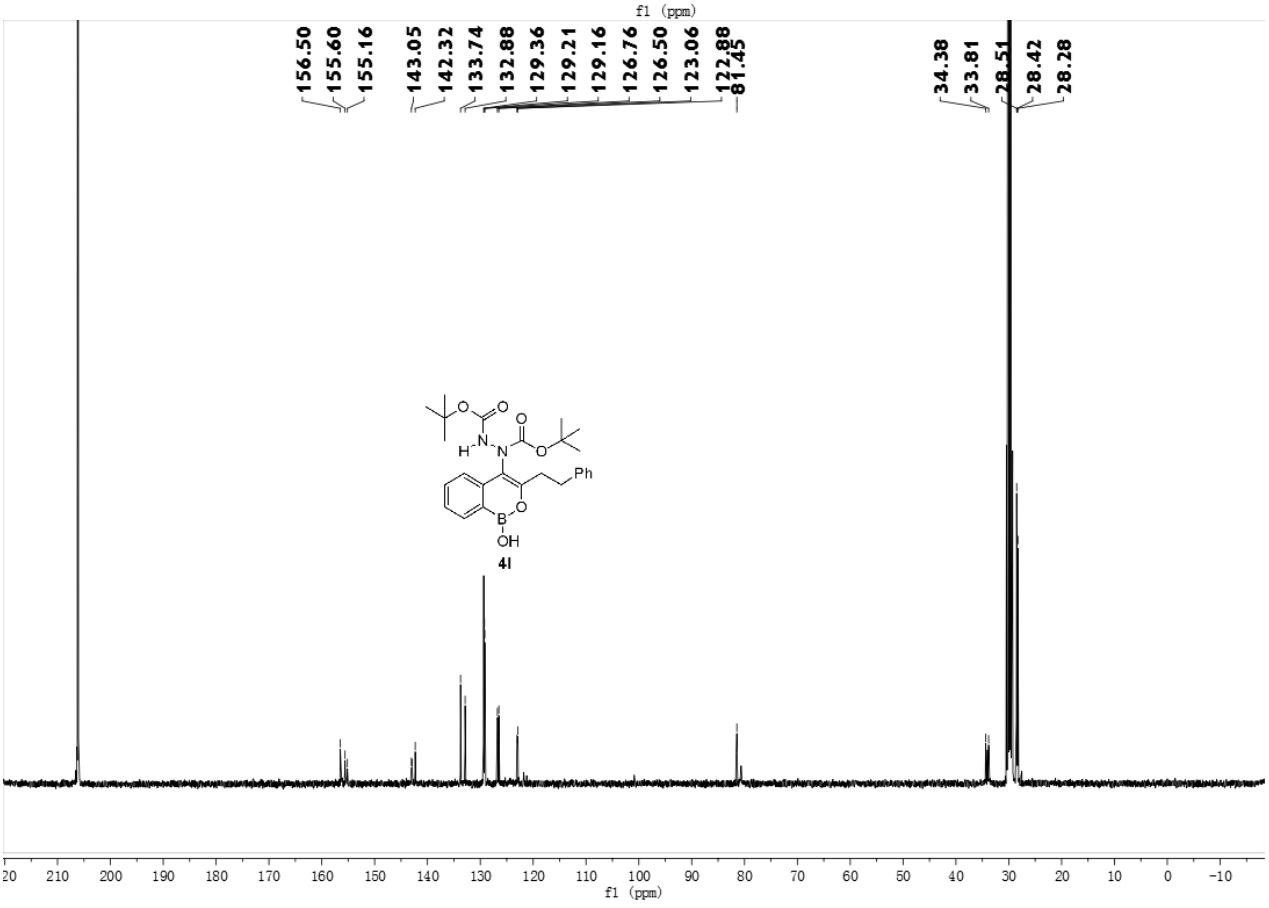

8.49
8.28
8.08
8.06
8.04
8.03
8.01
7.81
7.80
7.72
7.70
7.63
7.62
7.59
7.58
7.56
7.37
7.35
7.33
7.33
7.31
1.71
1.70
1.68
1.66
1.52
1.48
1.44
1.41
1.38
1.38
1.36
1.34
1.33
1.31
0.90
0.89
0.89
4j
0.73
0.78
1.04
1.00
1.04
1.00
1.86
1.94
24.04
3.26
f1 (ppm)

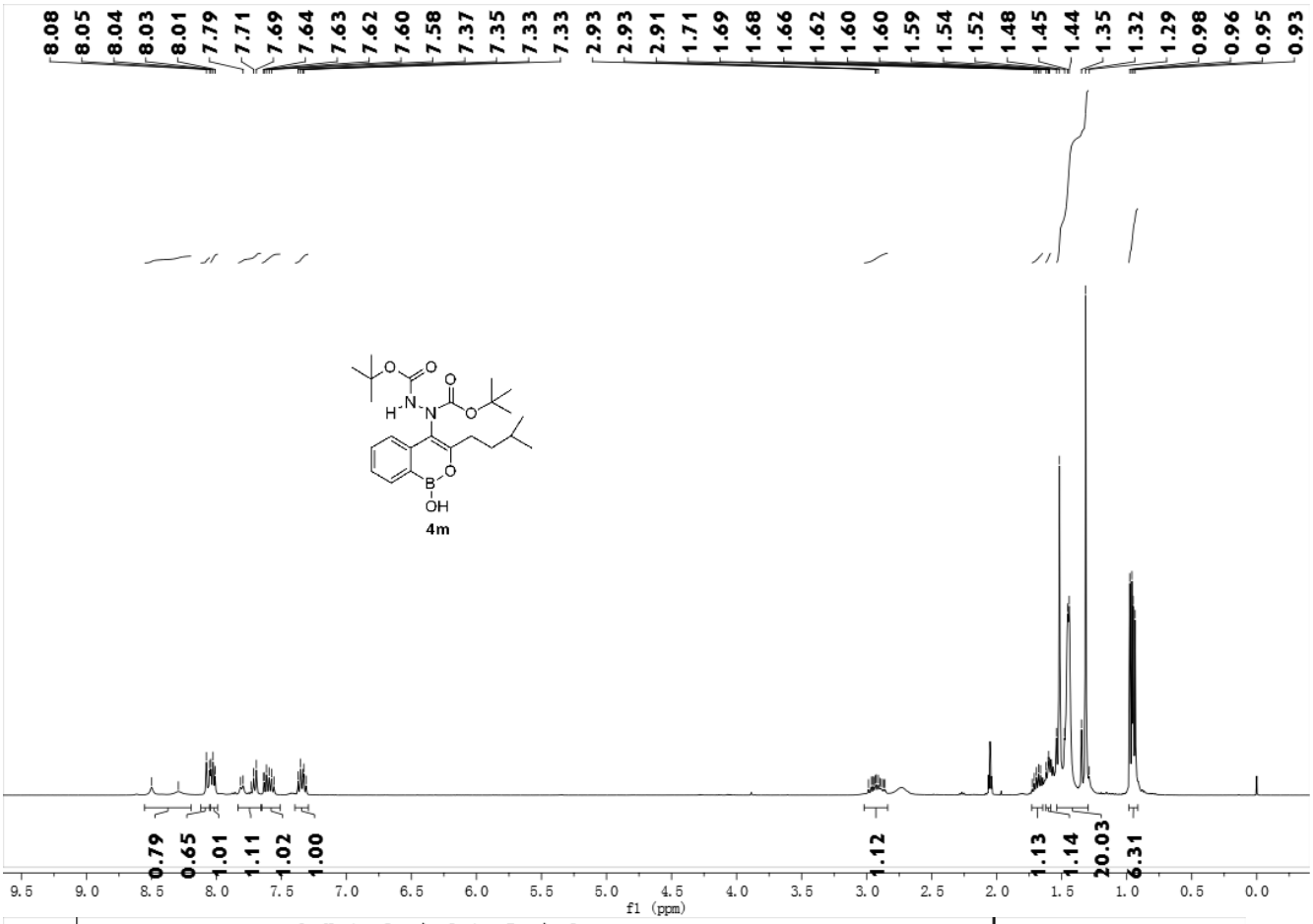

157.44
156.62
156.46
156.30
155.67
155.10
142.48
133.65
132.75
126.28
123.06
122.88
121.71
121.24
81.33
80.52
32.71
32.61
31.86
28.56
28.52
28.41
28.27
27.68
23.29
14.41
4j
f1 (ppm)

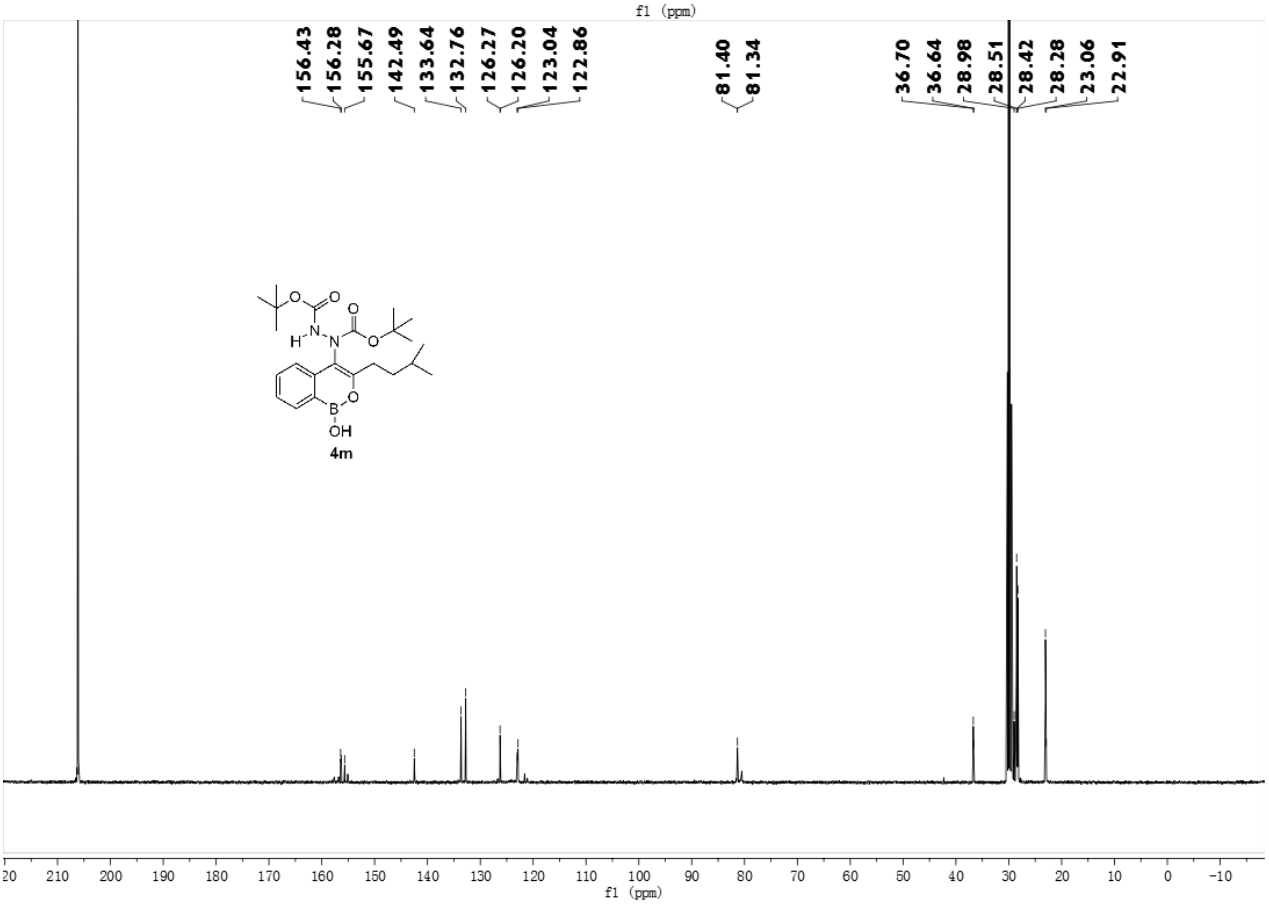

8.56
8.36
8.18
8.16
8.06
8.04
7.80
7.78
7.70
7.68
7.65
7.63
7.61
7.59
7.57
7.40
7.38
7.36
7.33
3.73
3.72
3.70
3.69
3.67
2.19
2.18
2.16
1.52
1.44
1.32
0.75
0.90
0.97
1.05
1.02
1.00
1.96
1.94
20.11
f1 (ppm)
4k

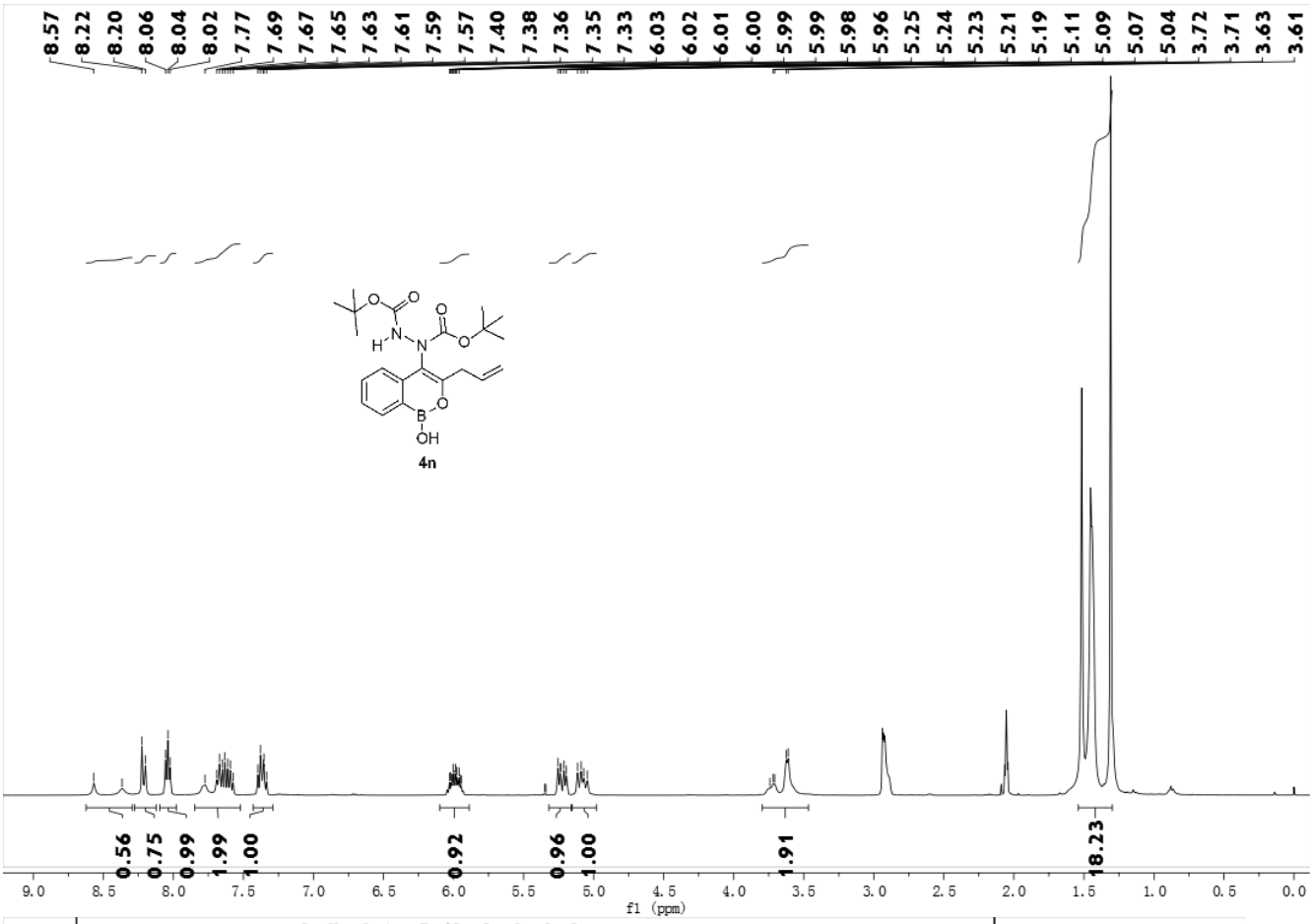

156.60
155.55
155.11
142.16
133.76
132.88
126.58
126.52
123.05
122.87
81.69
45.40
29.40
28.52
28.42
28.27
15.65
f1 (ppm)
4k

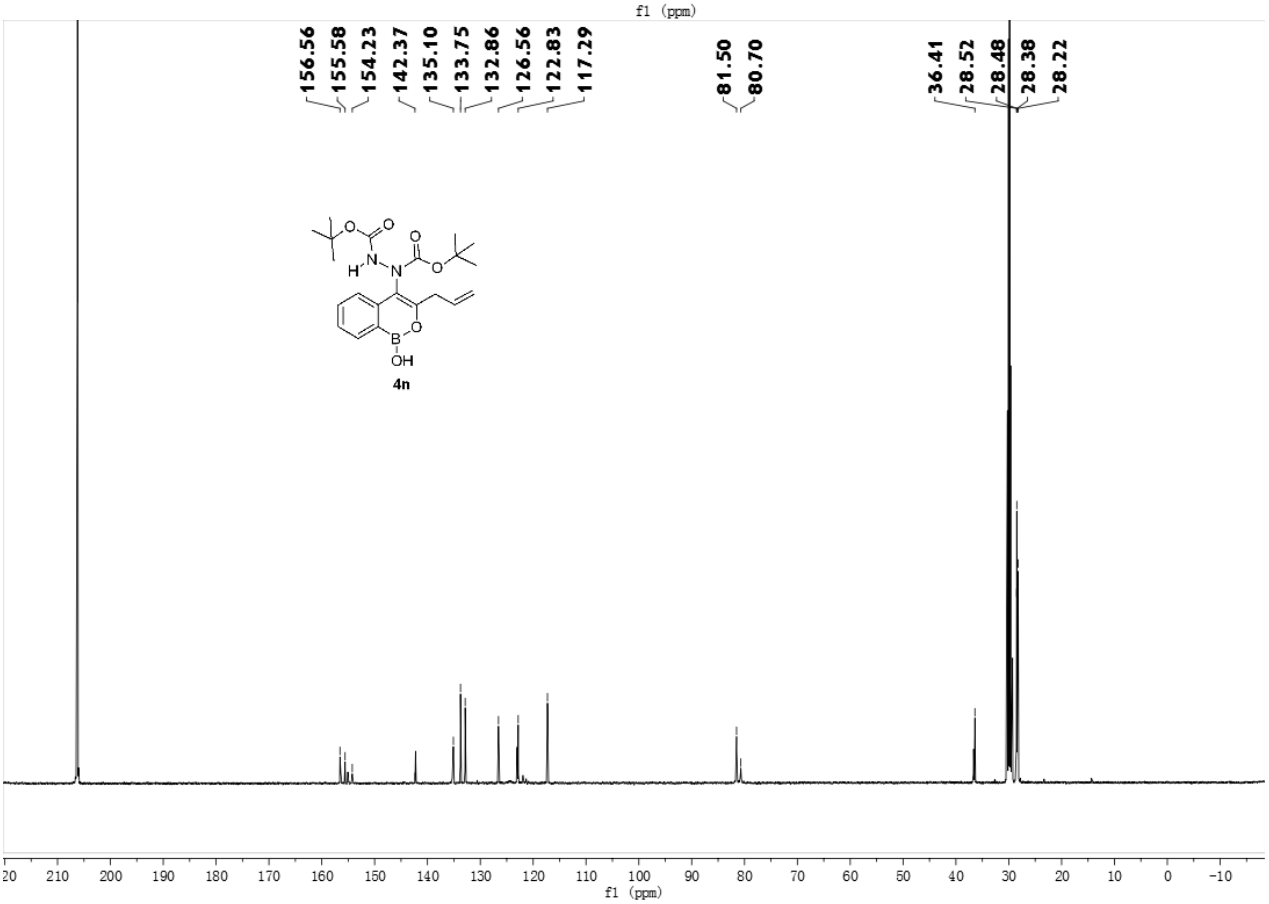

8.19
8.17
8.07
8.06
8.04
7.72
7.70
7.65
7.63
7.62
7.60
7.40
7.38
7.36
7.34
7.31
7.30
7.29
7.27
7.20
7.18
7.18
3.23
3.10
3.08
3.02
3.01
2.99
2.97
1.52
1.45
1.43
1.31
0.57
0.84
0.94
1.03
1.00
4.75
1.07
3.73
18.25
Ph
OH
4l
f1 (ppm)

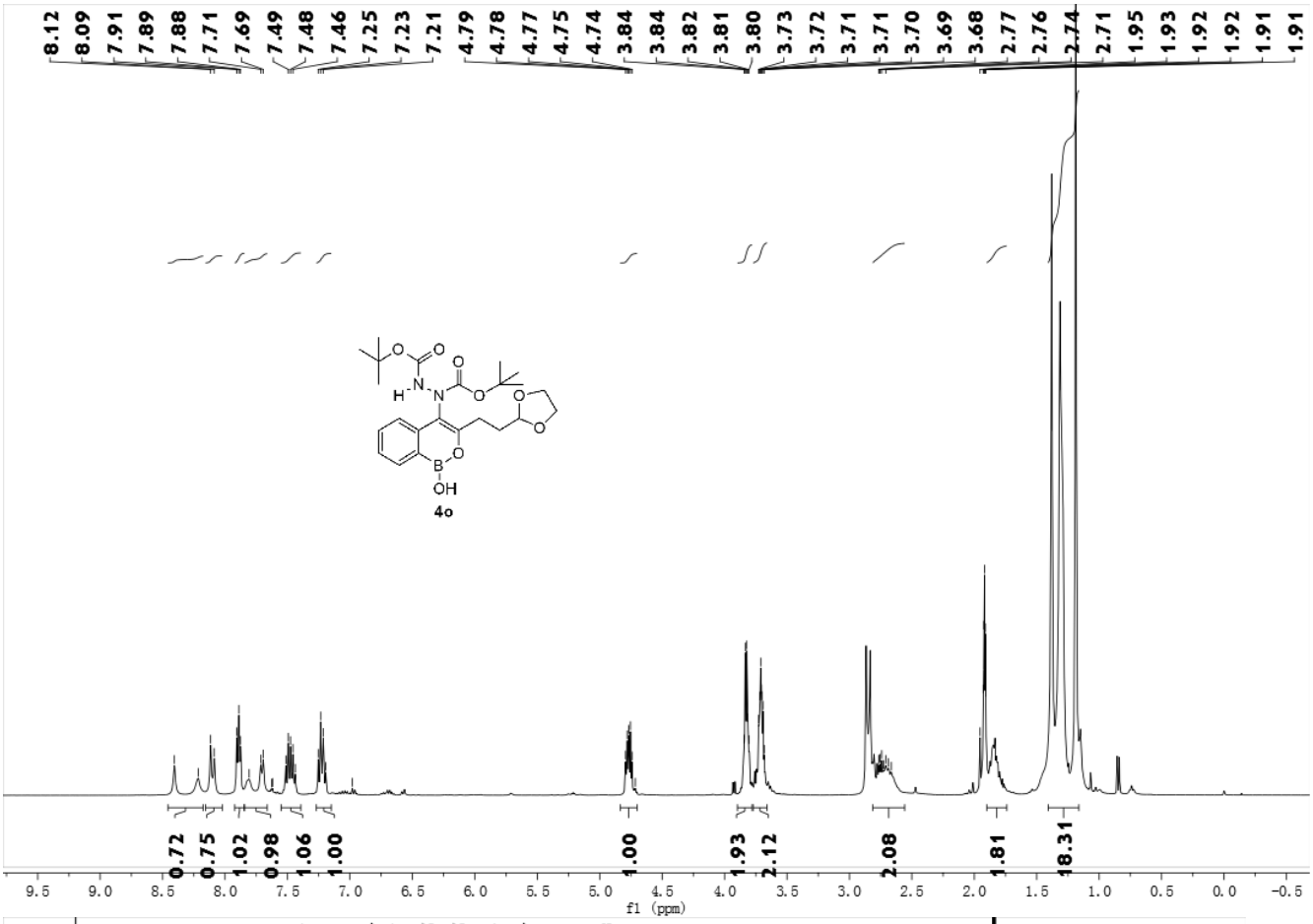

156.50
155.60
155.16
143.05
142.32
133.74
132.88
129.36
129.21
129.16
126.76
126.50
123.06
122.88
81.45
34.38
33.81
28.51
28.42
28.28
Ph
OH
4l
f1 (ppm)

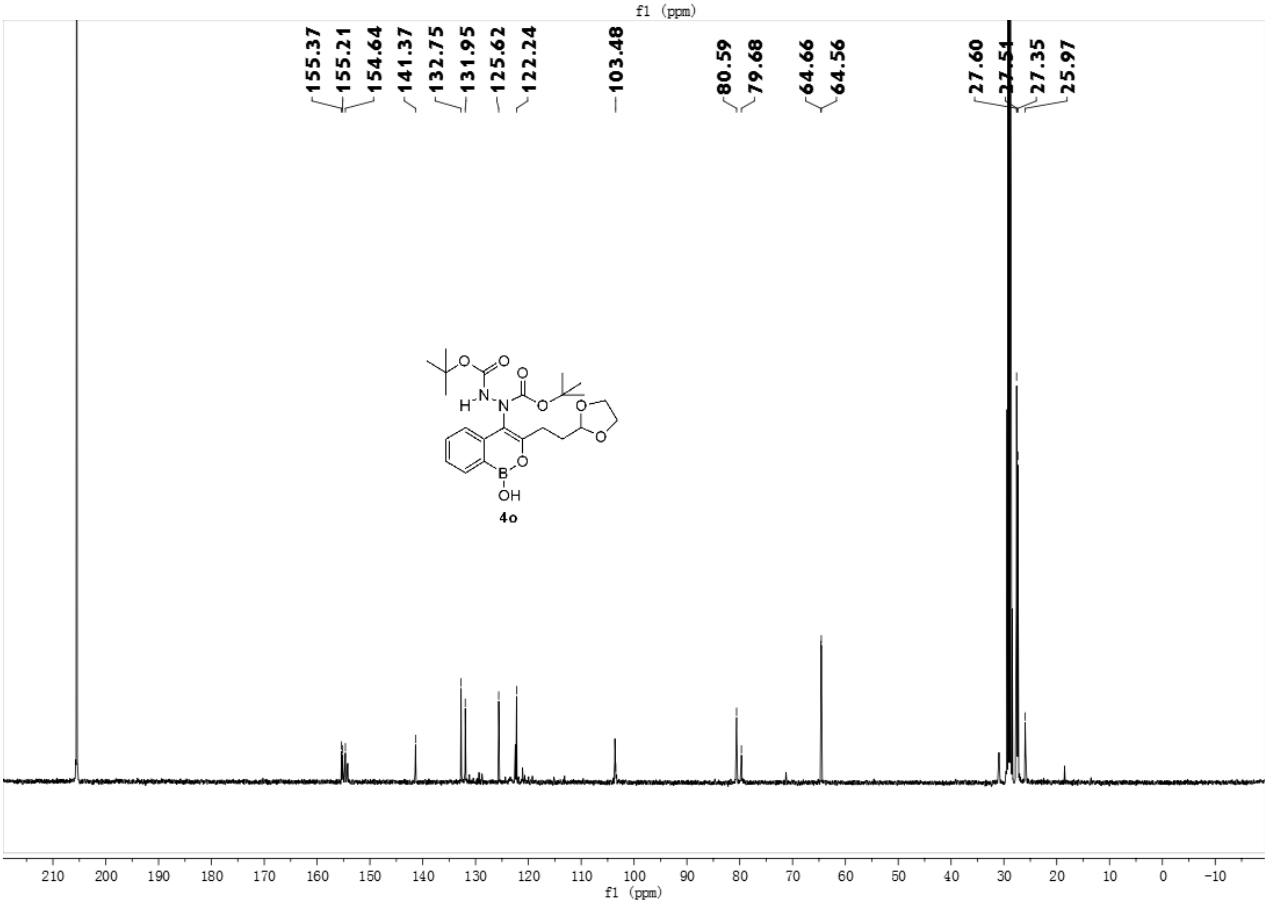

8.08 8.05 8.04 8.03 8.01 7.79 7.71 7.69 7.64 7.63 7.62 7.60 7.58 7.37 7.35 7.33 7.33
2.93 2.93 2.91 1.71 1.69 1.68 1.66 1.62 1.60 1.60 1.59 1.54 1.52 1.48 1.45 1.44 1.35 1.32 1.29 0.98 0.96 0.95 0.93
0.79 0.65 1.01 1.11 1.02 1.00 1.12 1.13 1.14 20.03 6.31
f1 (ppm)
4m

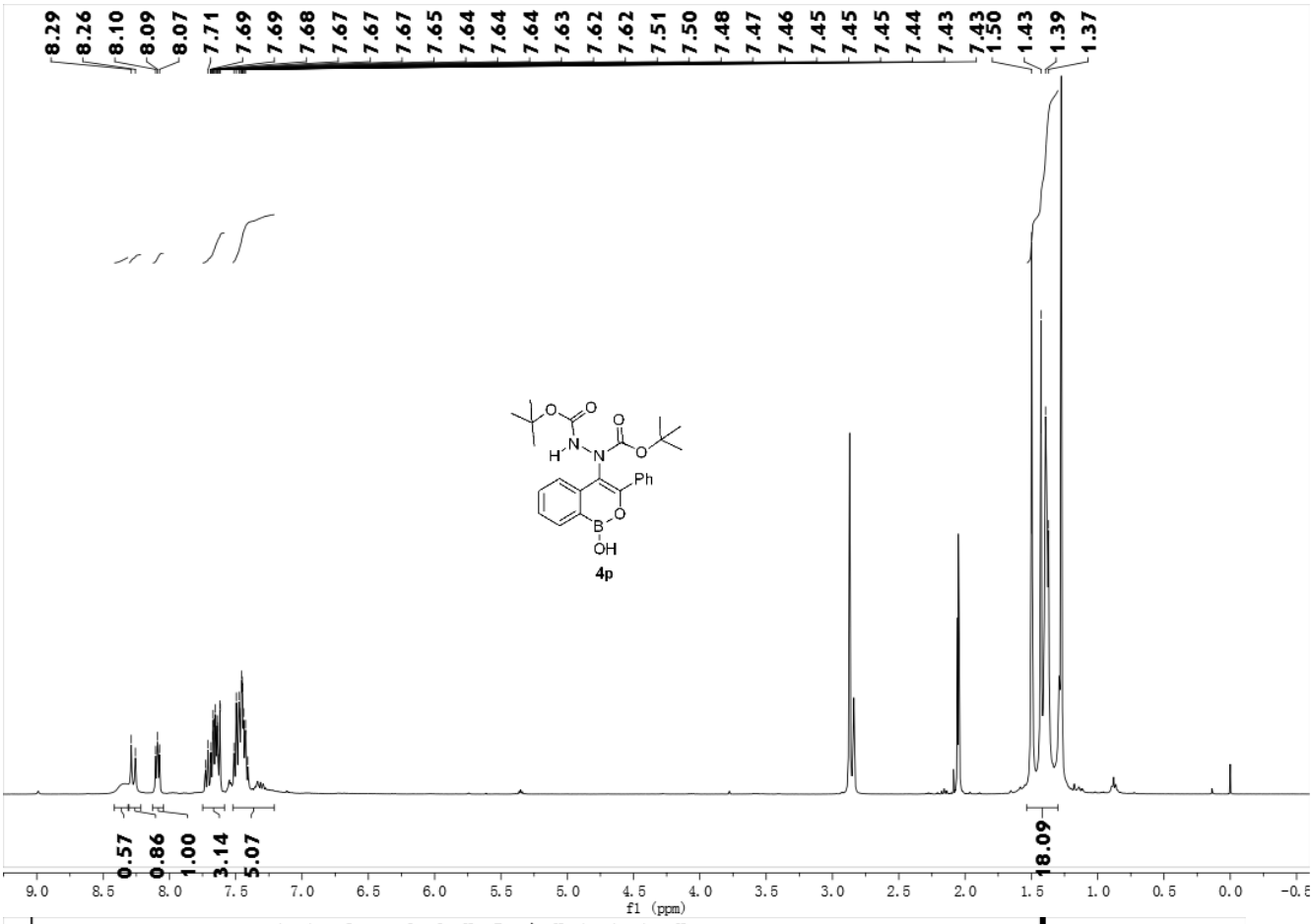

156.43 156.28 155.67 142.49 133.64 132.76 126.27 126.20 123.04 122.86
81.40 81.34
36.70 36.64 28.98 28.51 28.42 28.28 23.06 22.91
f1 (ppm)
4m

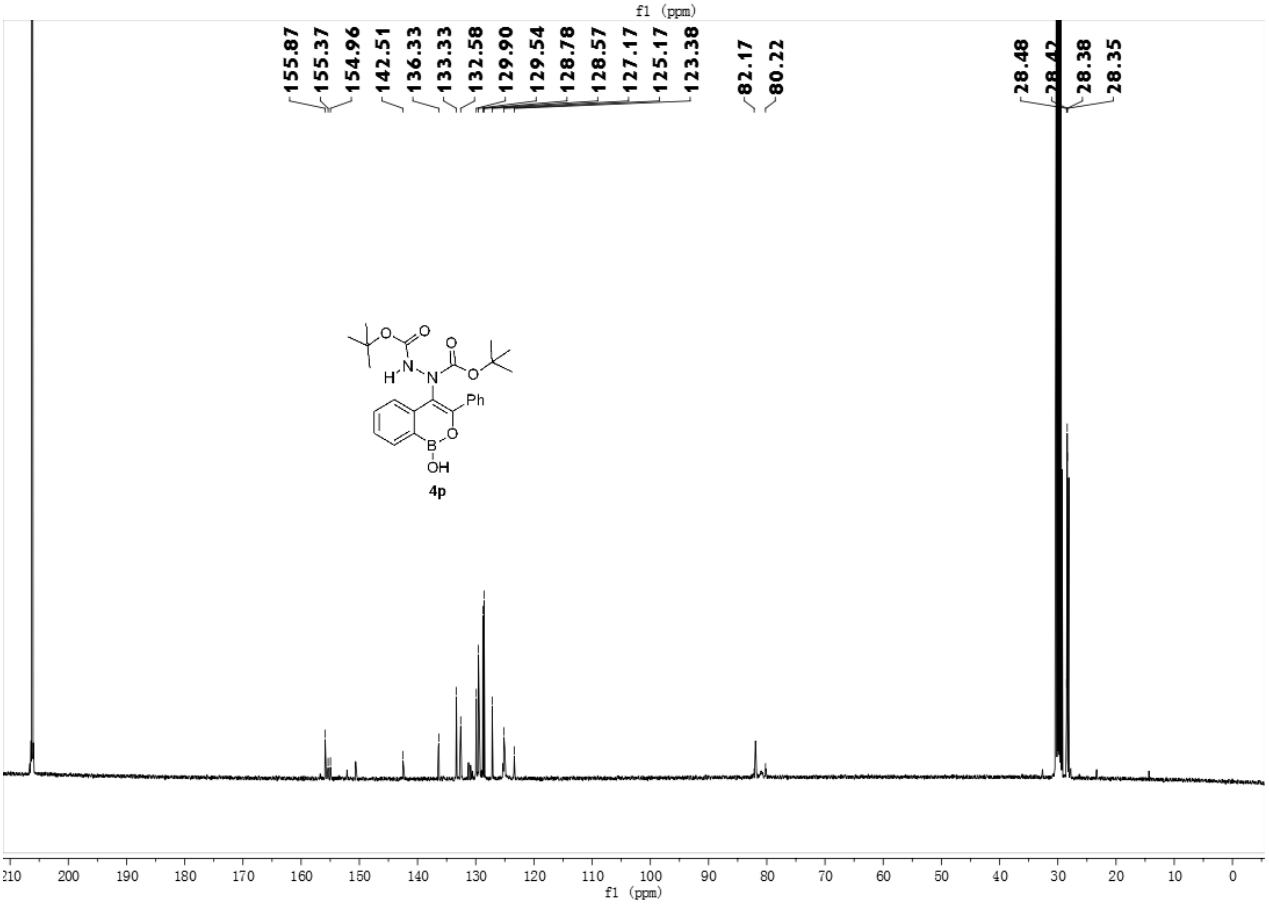

8.57
8.22
8.20
8.06
8.04
8.02
7.77
7.69
7.67
7.65
7.63
7.61
7.59
7.57
7.40
7.38
7.36
7.35
7.33
6.03
6.02
6.01
6.00
5.99
5.99
5.98
5.96
5.25
5.24
5.23
5.21
5.19
5.11
5.09
5.07
5.04
3.72
3.71
3.63
3.61
4n
0.56
0.75
0.99
1.99
1.00
0.92
0.96
1.00
1.91
18.23
f1 (ppm)

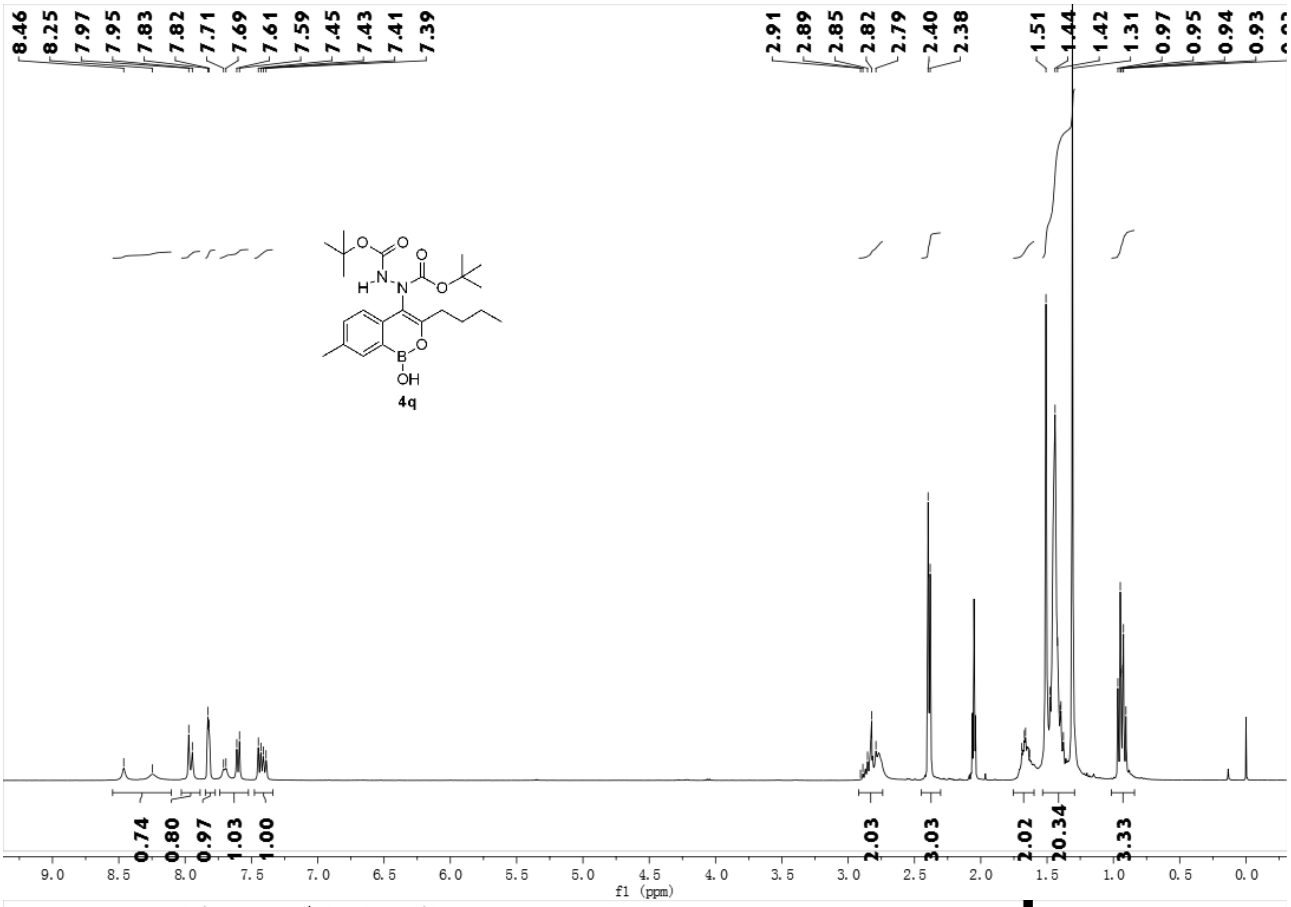

156.56
155.58
154.23
142.37
135.10
133.75
132.86
126.56
122.83
117.29
81.50
80.70
36.41
28.52
28.48
28.38
28.22
4n
f1 (ppm)

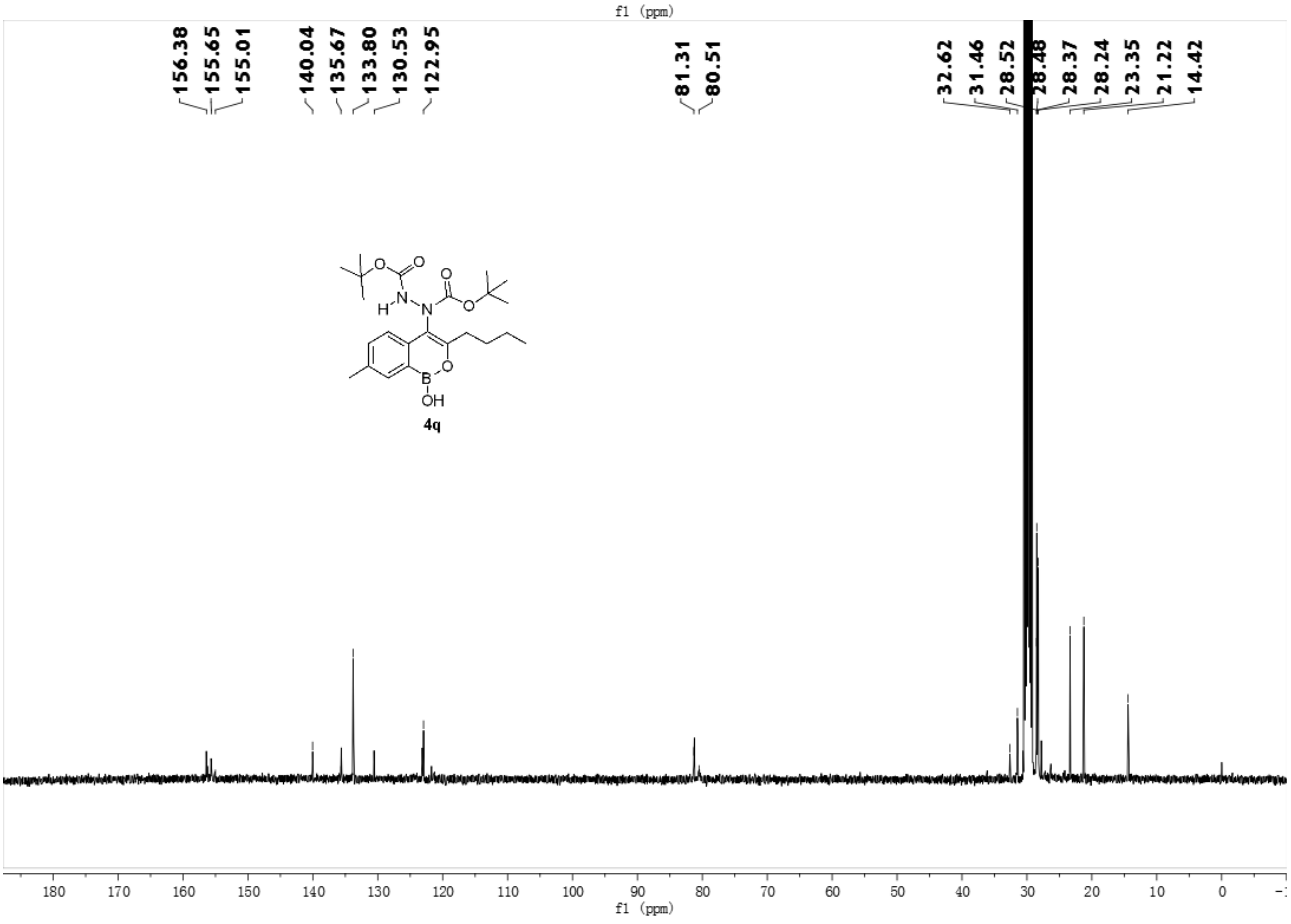

8.12 8.09 7.91 7.89 7.88 7.71 7.69 7.49 7.48 7.46 7.25 7.23 7.21
4.79 4.78 4.77 4.75 4.74 3.84 3.84 3.82 3.81 3.80 3.73 3.72 3.71 3.71 3.70 3.69 3.68 2.77 2.76 2.74 2.71 1.95 1.93 1.92 1.92 1.91 1.91
4o
0.72 0.75 1.02 0.98 1.06 1.00 1.00 1.93 2.12 2.08 1.81 18.31
f1 (ppm)

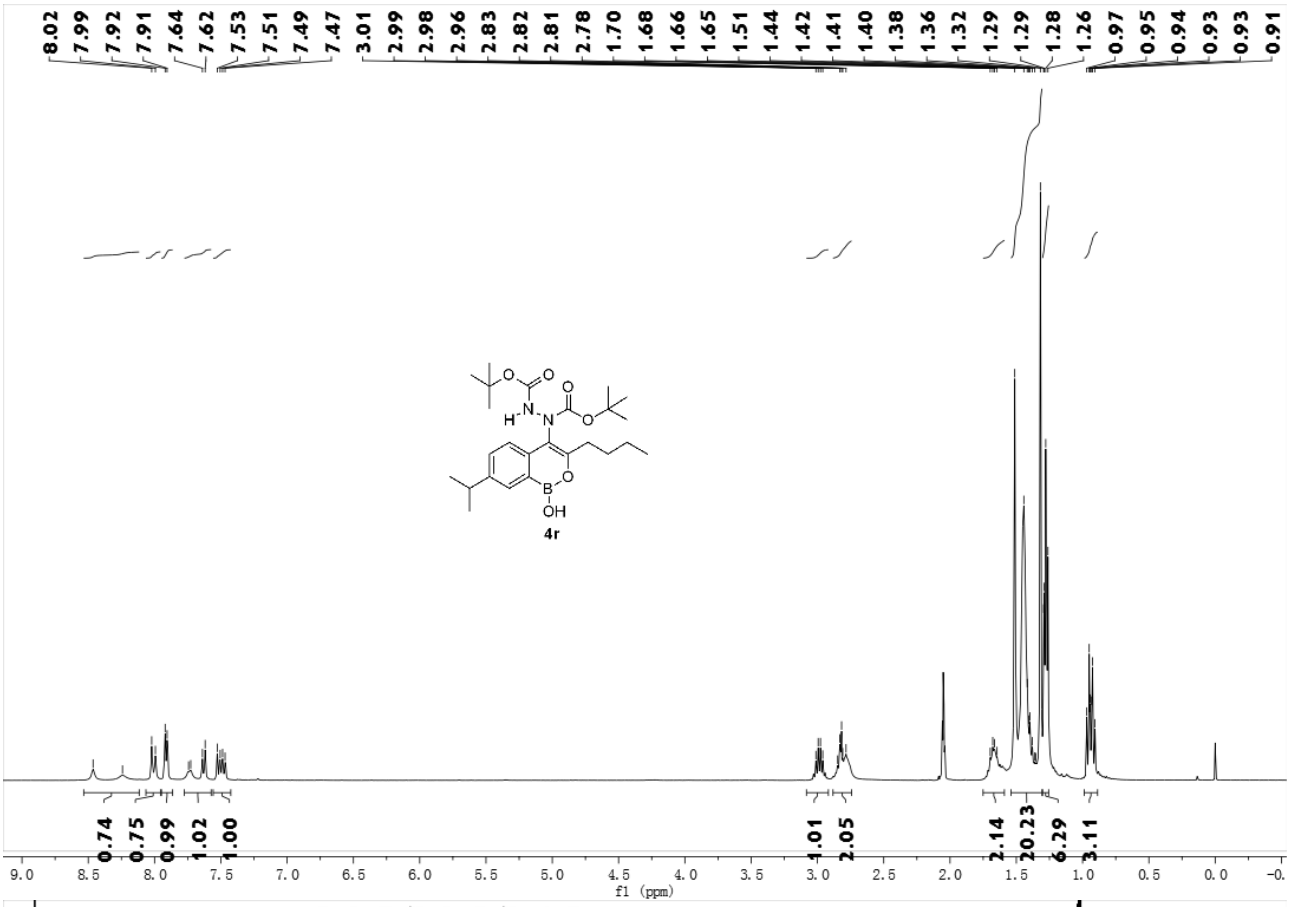

155.37 155.21 154.64 141.37 132.75 131.95 125.62 122.24 103.48 80.59 79.68 64.66 64.56 27.60 27.51 27.35 25.97
4o
f1 (ppm)

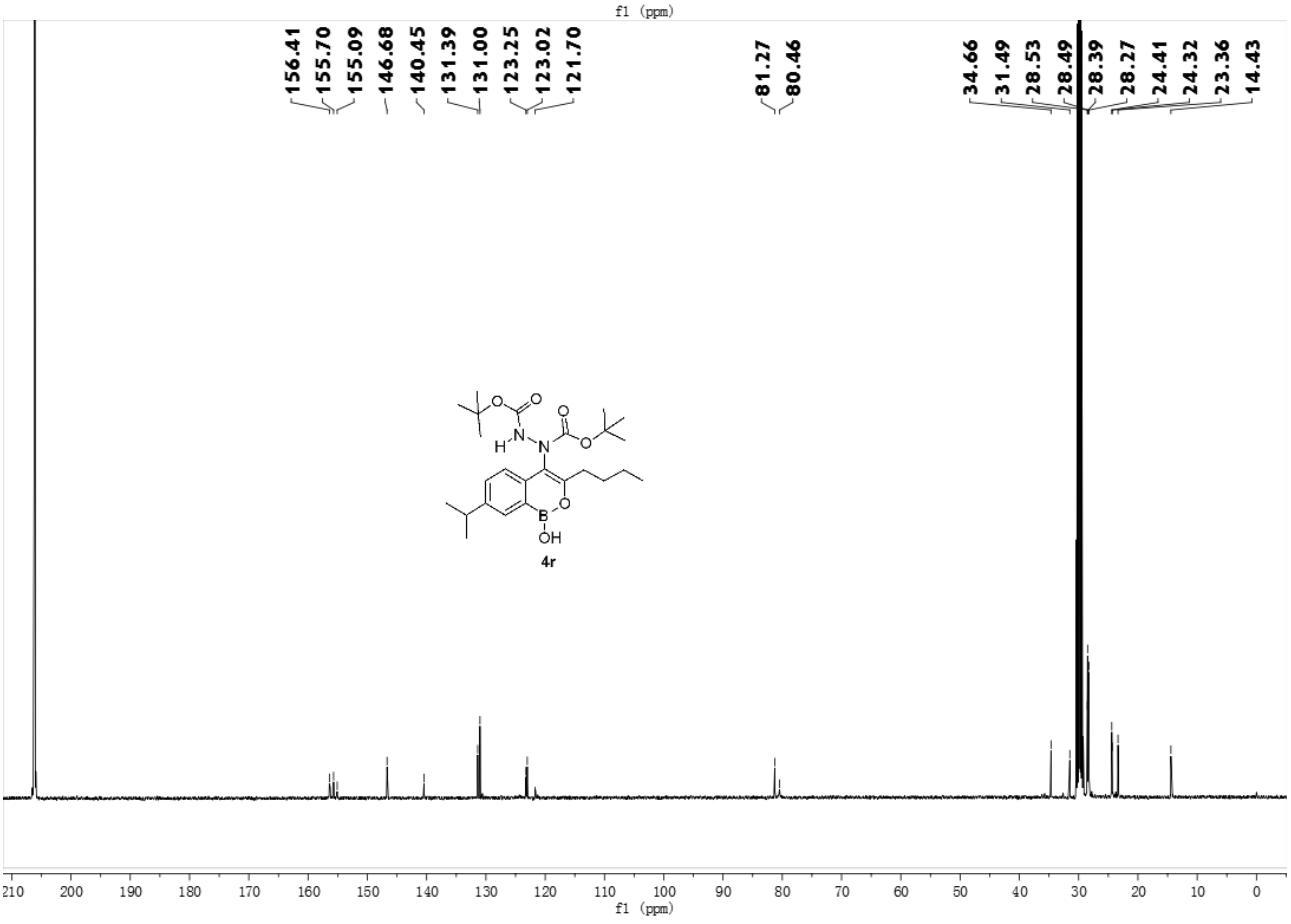

8.29
8.26
8.10
8.09
8.07
7.71
7.69
7.69
7.68
7.67
7.67
7.67
7.65
7.64
7.64
7.64
7.63
7.62
7.62
7.51
7.50
7.48
7.47
7.46
7.45
7.45
7.45
7.44
7.43
7.43
1.50
1.43
1.39
1.37
Ph
B
O
OH
4p
0.57
0.86
1.00
3.14
5.07
18.09
f1 (ppm)

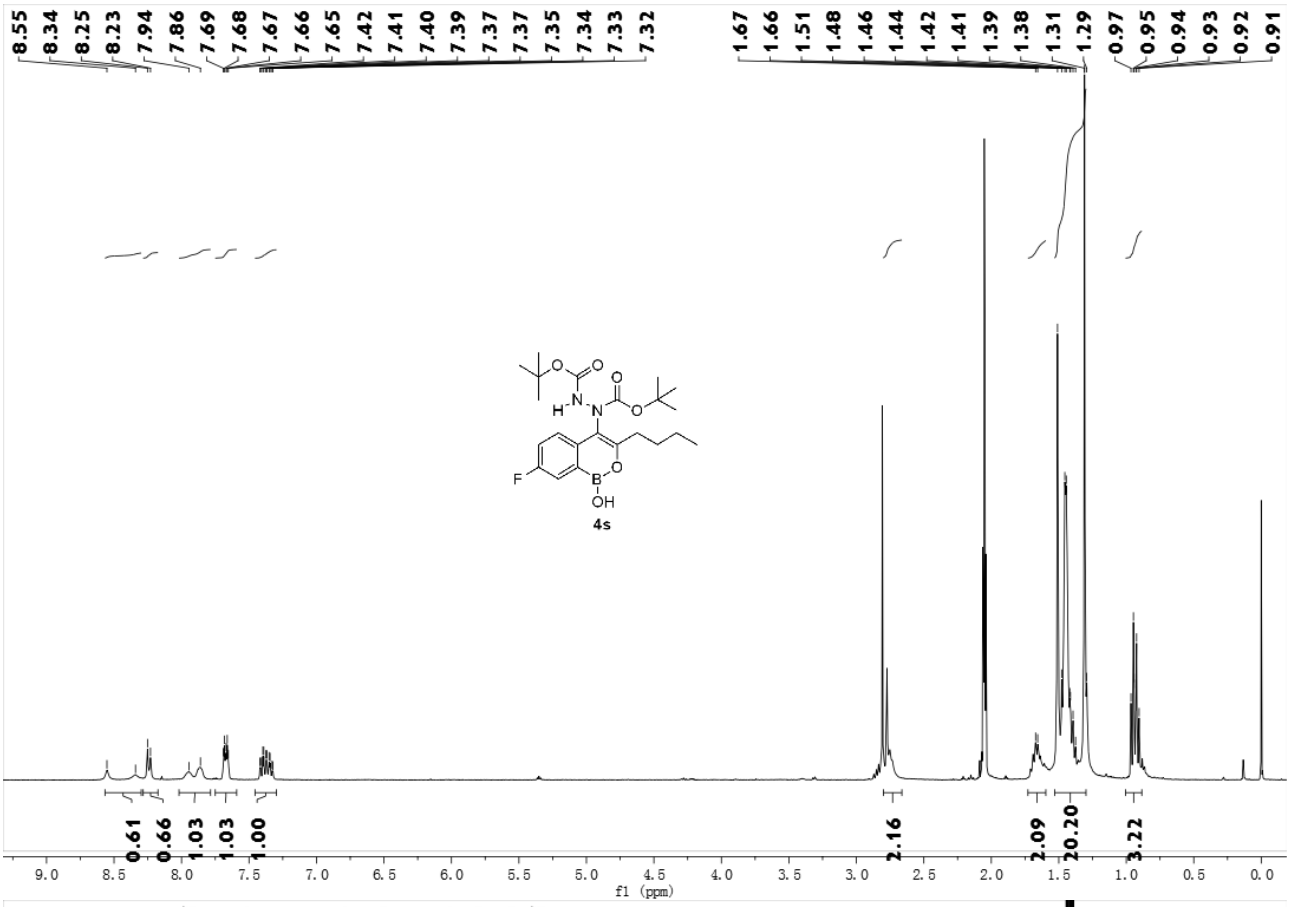

155.87
155.37
154.96
142.51
136.33
133.33
132.58
129.90
129.54
128.78
128.57
127.17
125.17
123.38
82.17
80.22
28.48
28.42
28.38
28.35
Ph
B
O
OH
4p
f1 (ppm)

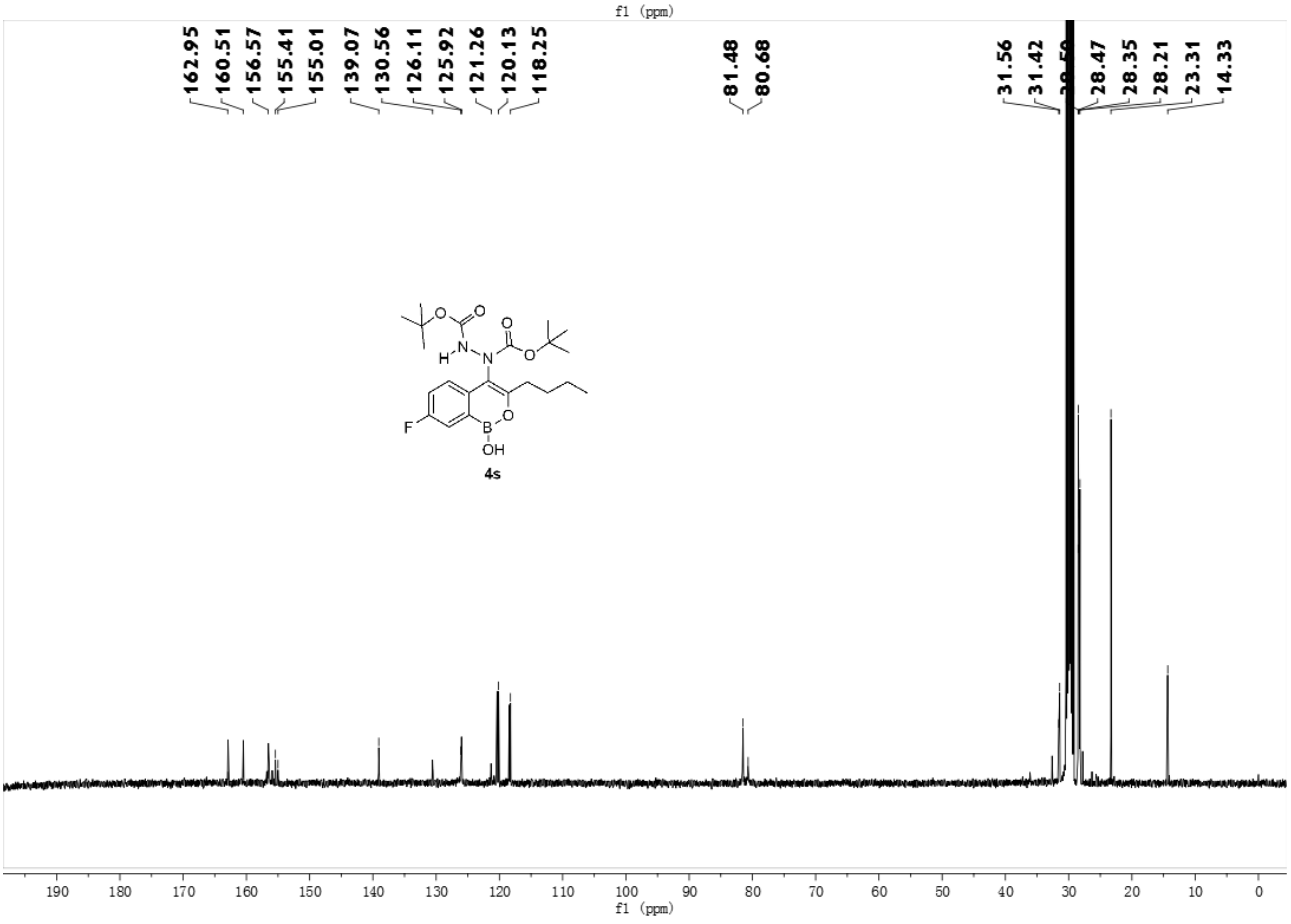

8.46
8.25
7.97
7.95
7.83
7.82
7.71
7.69
7.61
7.59
7.45
7.43
7.41
7.39
2.91
2.89
2.85
2.82
2.79
2.40
2.38
1.51
1.44
1.42
1.31
0.97
0.95
0.94
0.93
0.74
0.80
0.97
1.03
1.00
2.03
3.03
2.02
20.34
3.33
f1 (ppm)
4q

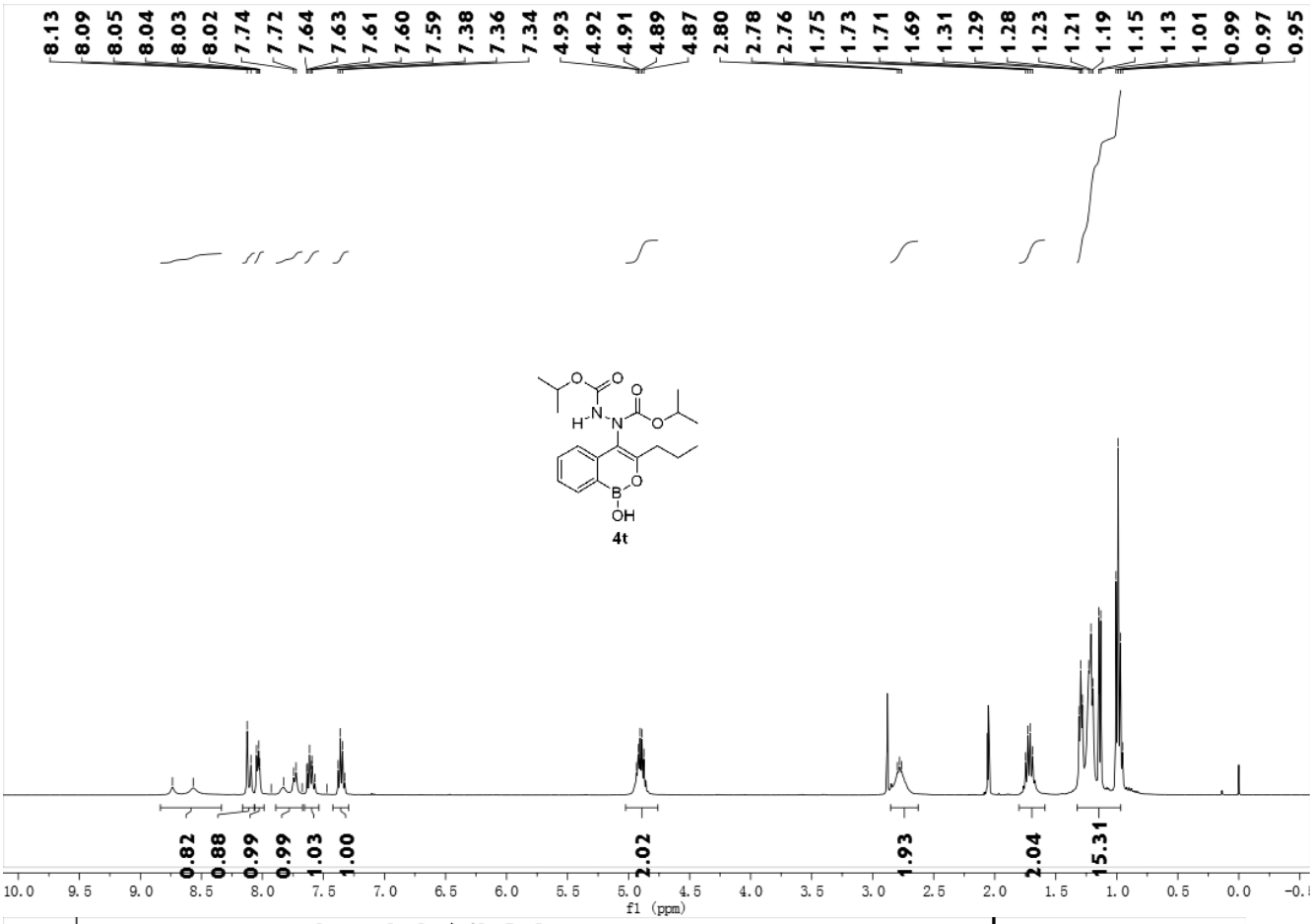

156.38
155.65
155.01
140.04
135.67
133.80
130.53
122.95
81.31
80.51
32.62
31.46
28.52
28.48
28.37
28.24
23.35
21.22
14.42
f1 (ppm)
4q

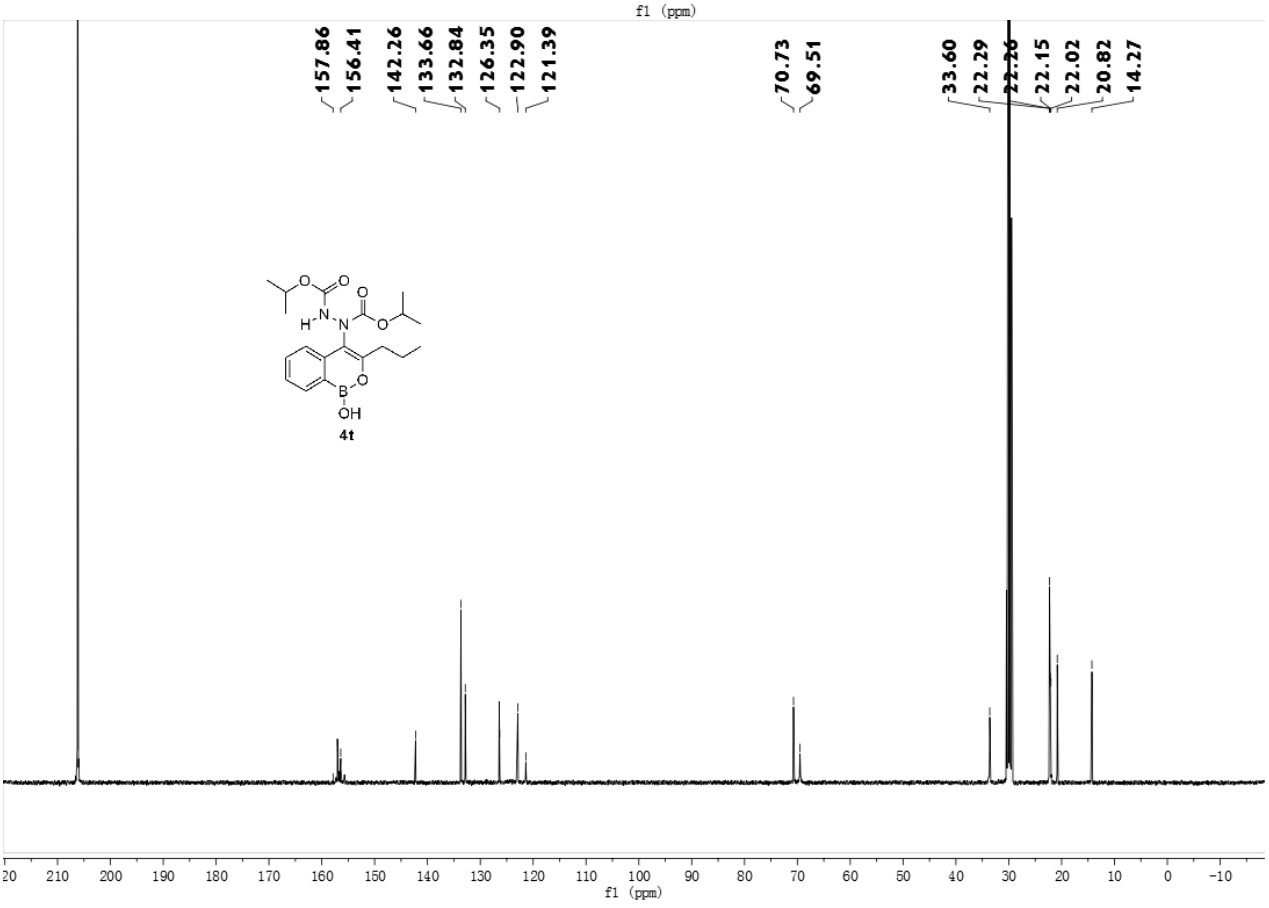

8.02 7.99 7.92 7.91 7.64 7.62 7.53 7.51 7.49 7.47 3.01 2.99 2.98 2.96 2.83 2.82 2.81 2.78 1.70 1.68 1.66 1.65 1.51 1.44 1.42 1.41 1.40 1.38 1.36 1.32 1.29 1.29 1.28 1.26 0.97 0.95 0.94 0.93 0.93 0.91
0.74 0.75 0.99 1.02 1.00 1.01 2.05 2.14 20.23 6.29 3.11
f1 (ppm)
4r


156.41 155.70 155.09 146.68 140.45 131.39 131.00 123.25 123.02 121.70 81.27 80.46 34.66 31.49 28.53 28.49 28.39 28.27 24.41 24.32 23.36 14.43
f1 (ppm)
4r

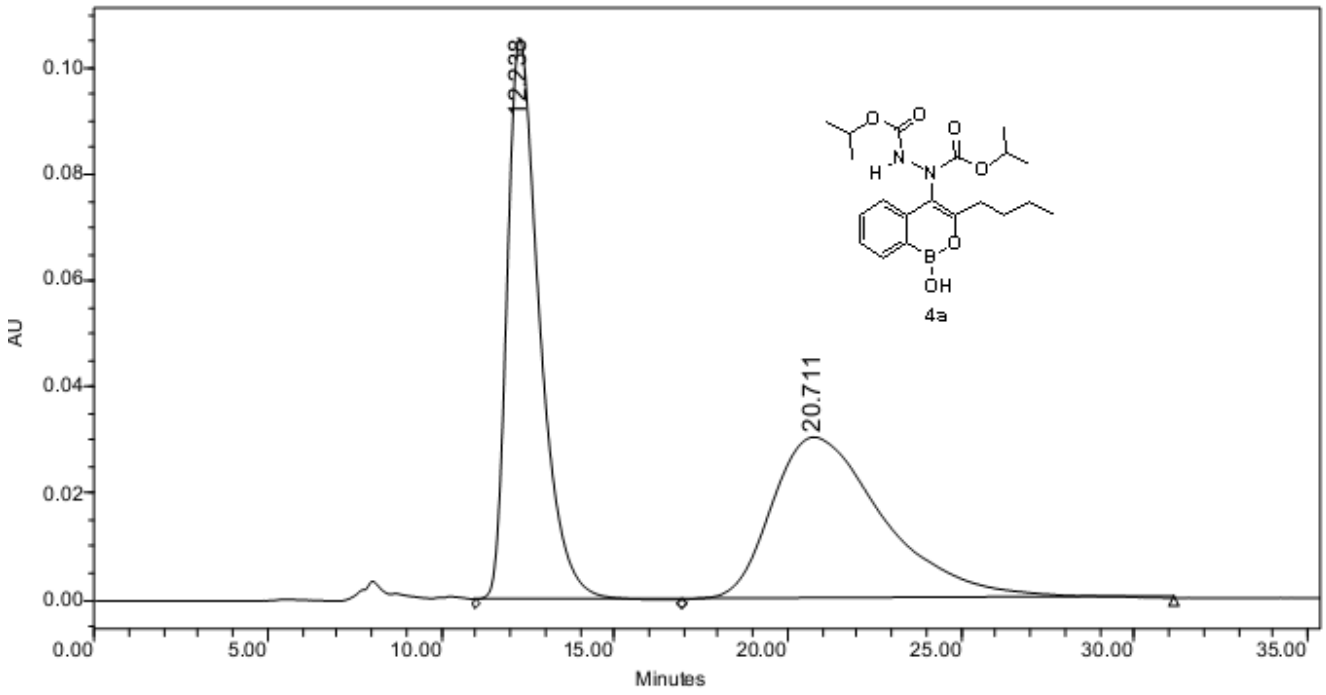

8.55 8.34 8.25 8.23 7.94 7.86 7.69 7.68 7.67 7.66 7.65 7.42 7.41 7.40 7.39 7.37 7.37 7.35 7.34 7.33 7.32
1.67 1.66 1.51 1.48 1.46 1.44 1.42 1.41 1.39 1.38 1.31 1.29 0.97 0.95 0.94 0.93 0.92 0.91
0.61 0.66 1.03 1.03 1.00 2.16 2.09 20.20 3.22
f1 (ppm)
4s


162.95 160.51 156.57 155.41 155.01 139.07 130.56 126.11 125.92 121.26 120.13 118.25
81.48 80.68
31.56 31.42 28.47 28.35 28.21 23.31 14.33
f1 (ppm)
4s

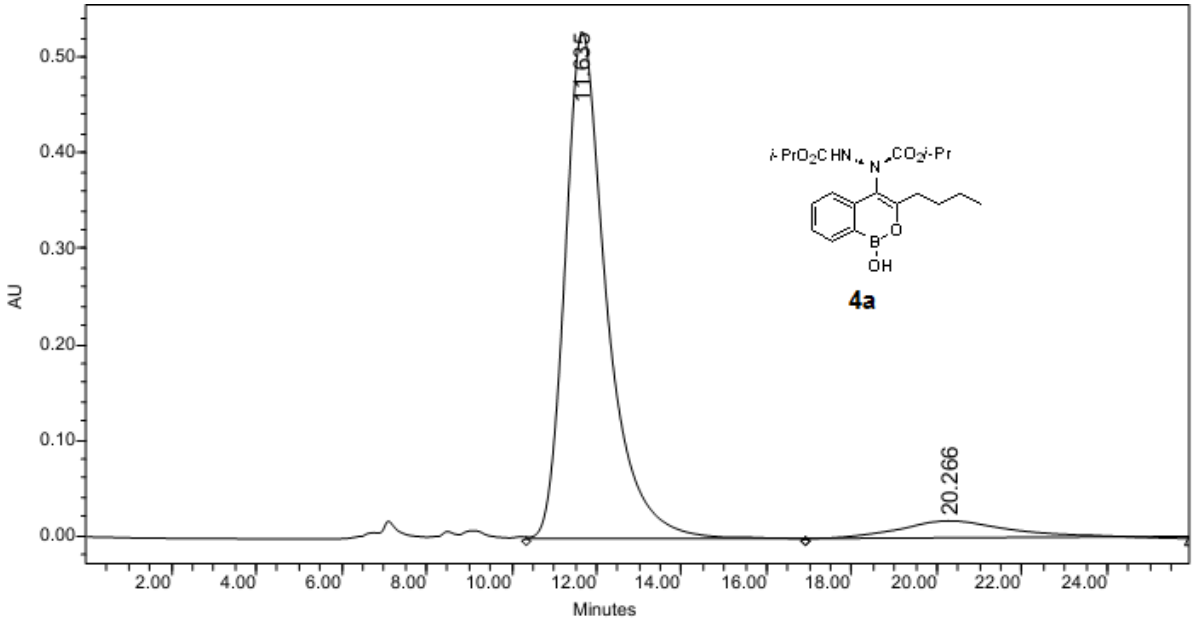

8.13 8.09 8.05 8.04 8.03 8.02 7.74 7.72 7.64 7.63 7.61 7.60 7.59 7.38 7.36 7.34 4.93 4.92 4.91 4.89 4.87 2.80 2.78 2.76 1.75 1.73 1.71 1.69 1.31 1.29 1.28 1.23 1.21 1.19 1.15 1.13 1.01 0.99 0.97 0.95
4t
0.82 0.88 0.99 0.99 1.03 1.00 2.02 1.93 2.04 15.31
f1 (ppm)


157.86 156.41 142.26 133.66 132.84 126.35 122.90 121.39 70.73 69.51 33.60 22.29 22.26 22.15 22.02 20.82 14.27
4t
f1 (ppm)

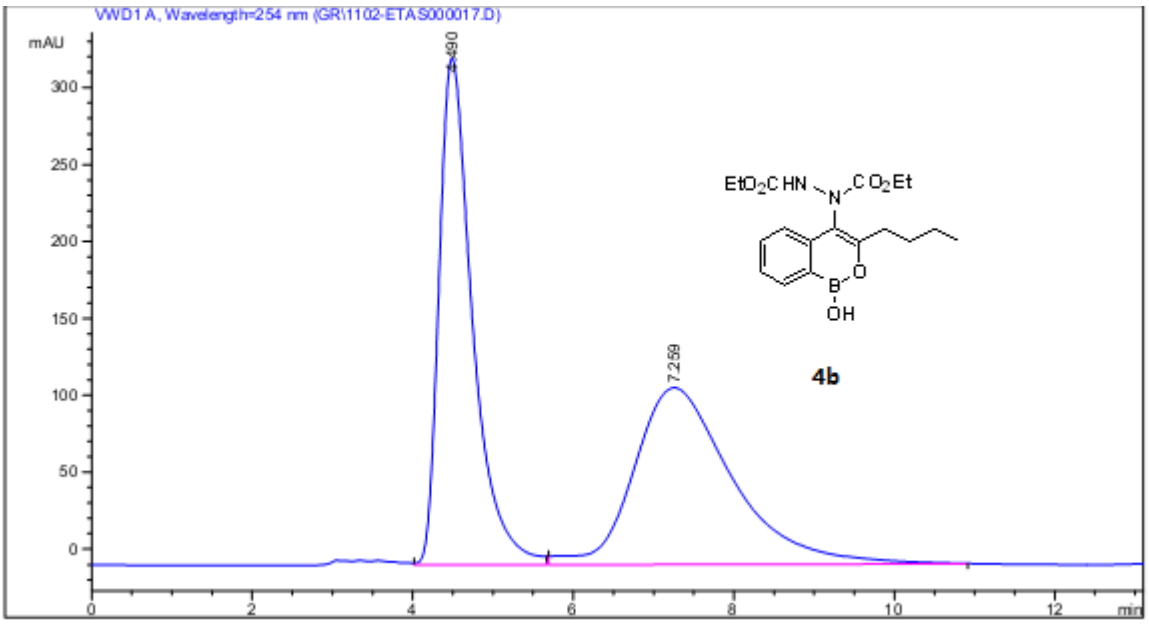
Part III Copies of HPLC Spectra of compounds



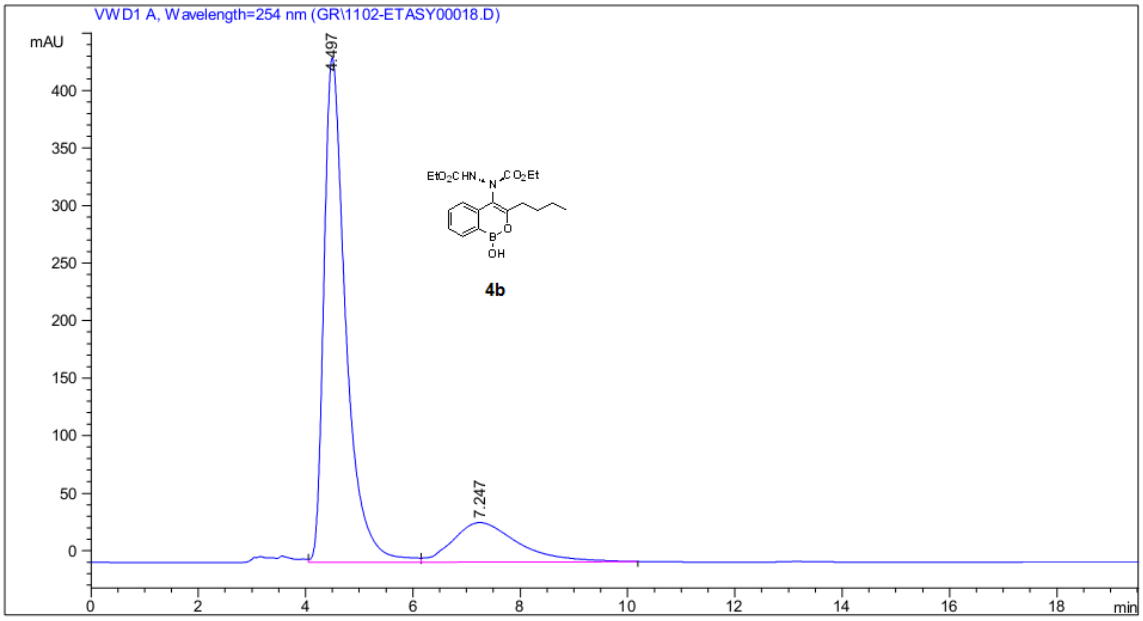
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	12.238	6904031	49.82	105748	77.62
2	20.711	6954121	50.18	30491	22.38



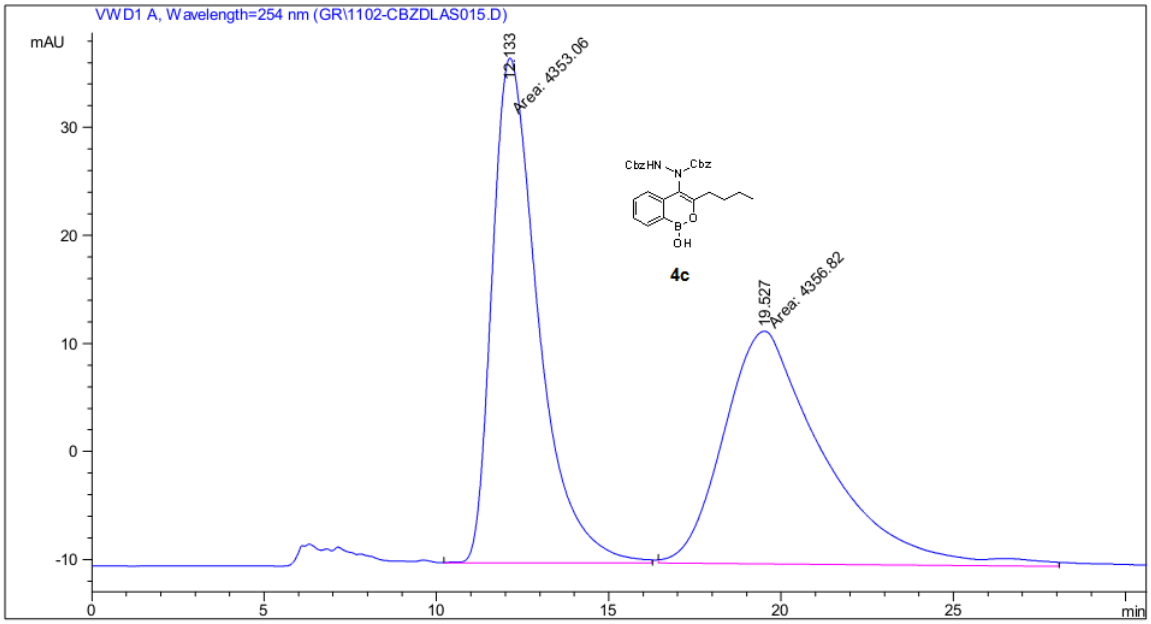
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	11.635	36106343	90.77	529828	96.61
2	20.266	3671232	9.23	18581	3.39



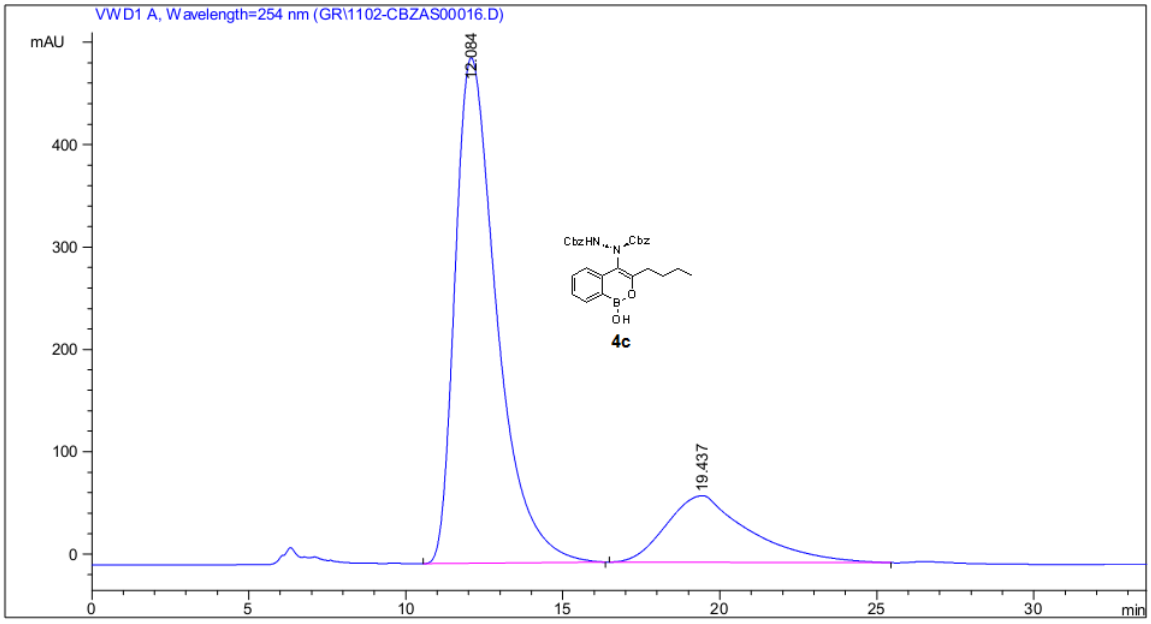
Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	4.490	VB	0.4383	9543.44629	329.53091	49.3887
2	7.259	BB	1.2722	9779.70898	114.77032	50.6113



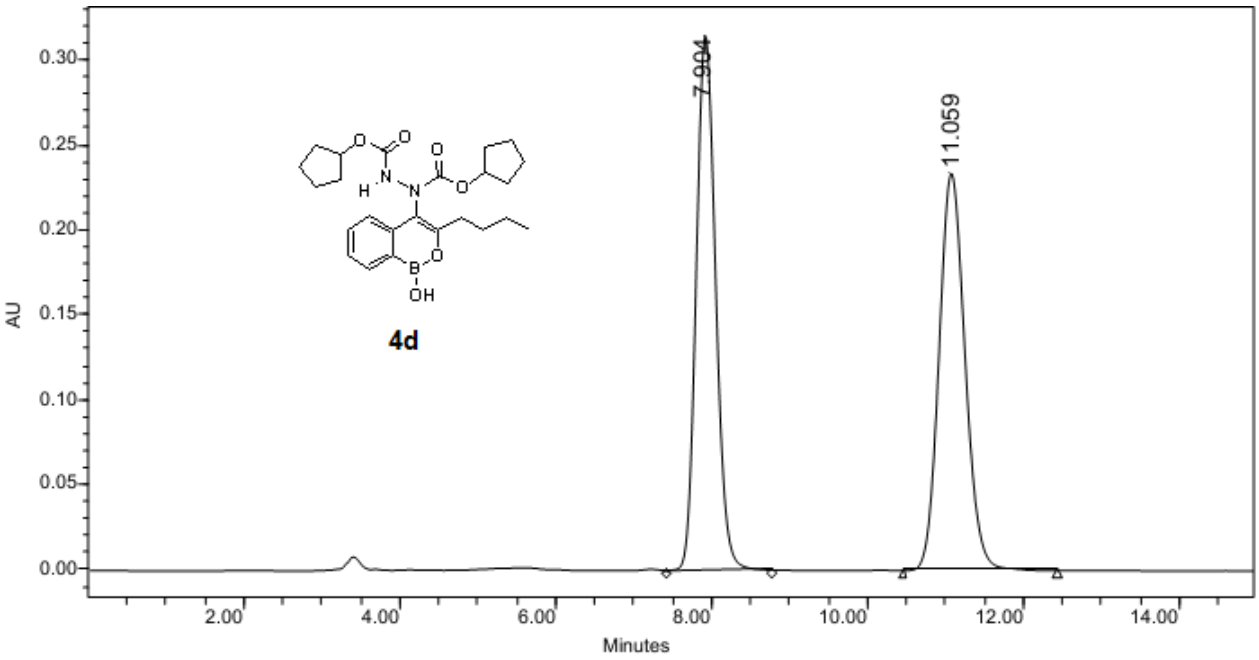
Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	4.497	VB	0.4255	1.24388e4	438.57407	81.1977
2	7.247	BB	1.2515	2880.34668	34.21429	18.8023



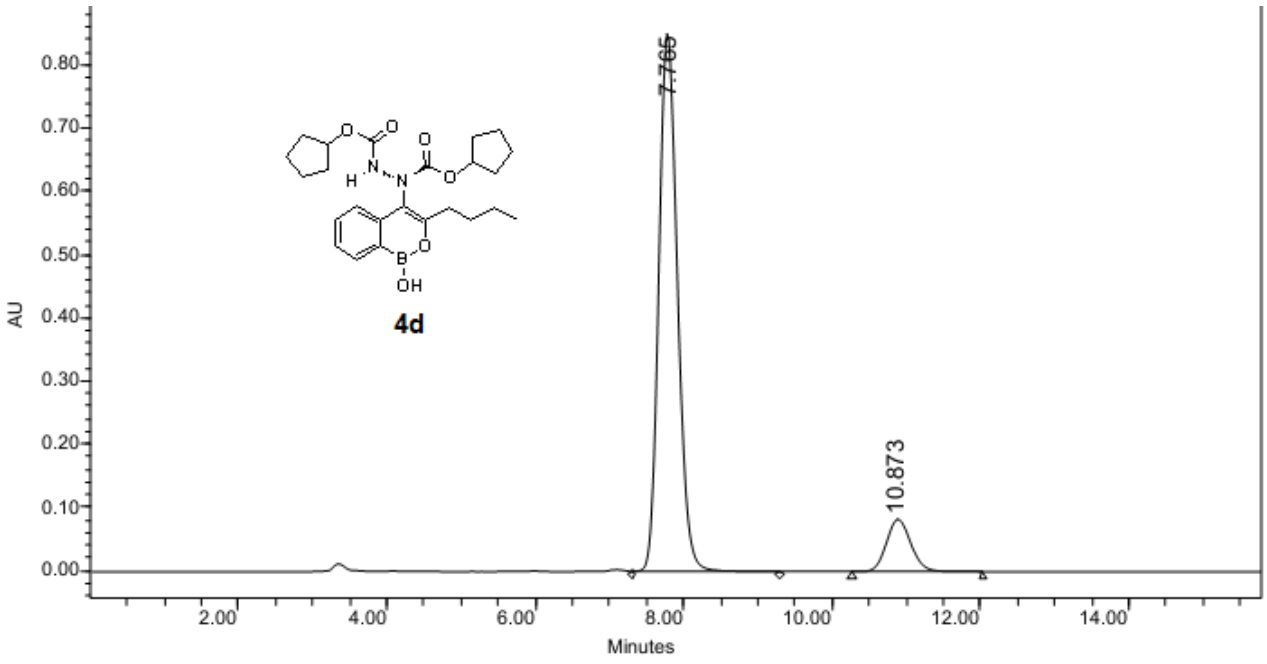
Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	12.133	MM	1.5524	4353.05762	46.73408	49.9784
2	19.527	MM	3.3723	4356.81836	21.53232	50.0216



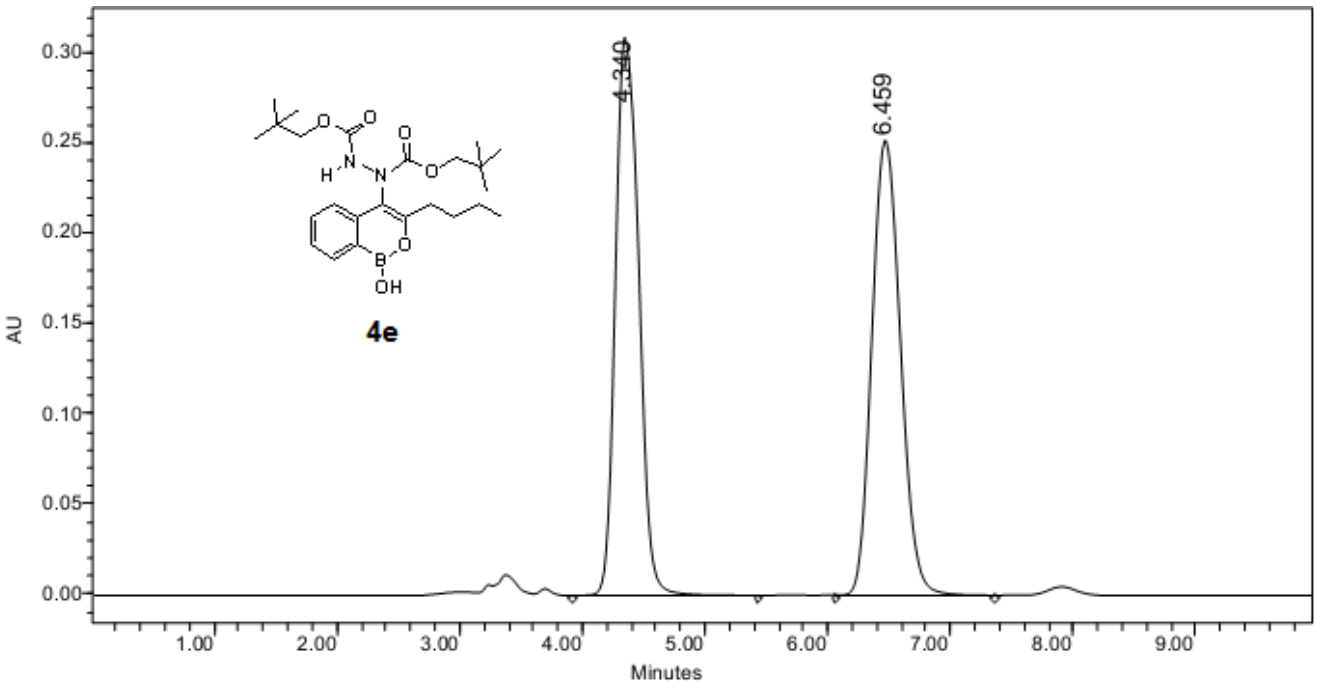
Peak #	RetTime [min]	Type	Width [min]	Area mAU *s	Height [mAU]	Area %
1	12.084	BB	1.3666	4.55751e4	493.74927	79.3105
2	19.437	BB	2.4724	1.18890e4	65.06937	20.6895



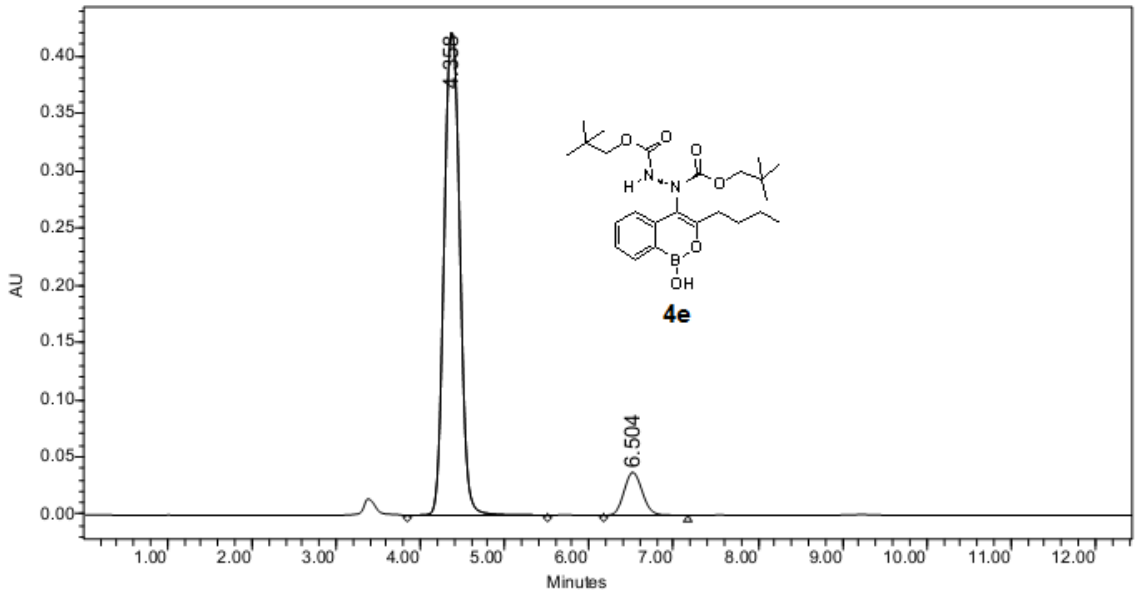
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	7.904	5448253	50.11	315120	57.41
2	11.059	5424392	49.89	233790	42.59



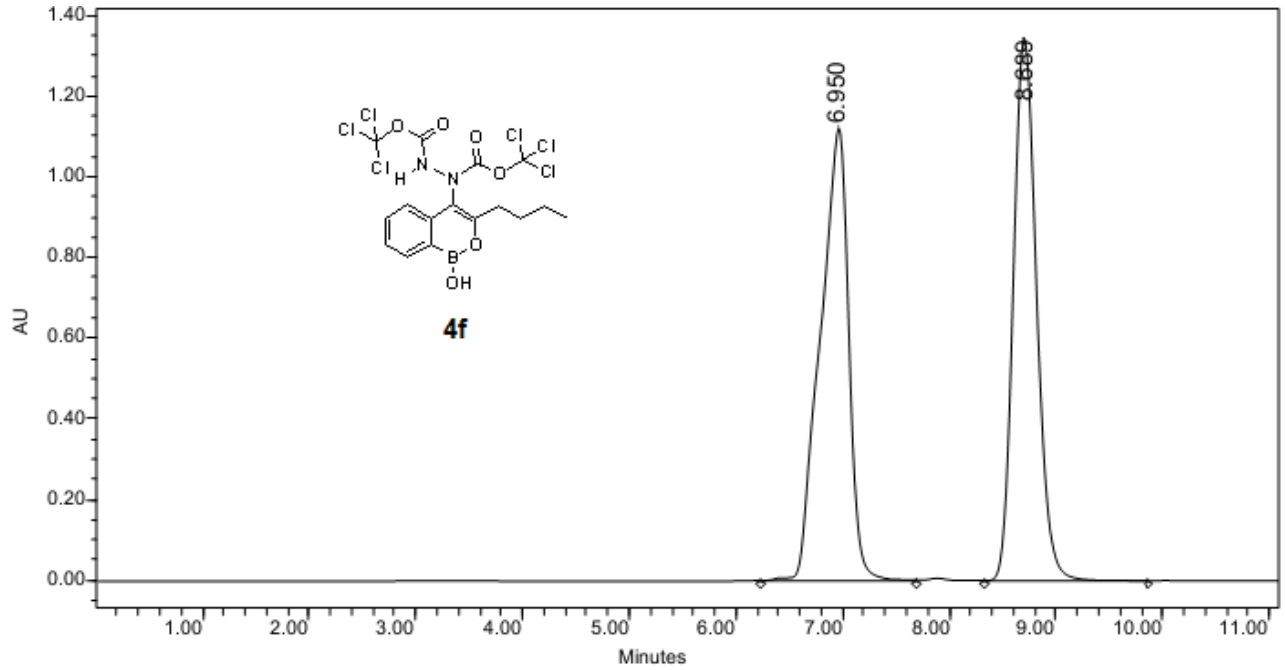
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	7.765	14847857	88.63	850902	91.15
2	10.873	1904760	11.37	82636	8.85



	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.340	4104965	50.01	310041	55.12
2	6.459	4103728	49.99	252482	44.88

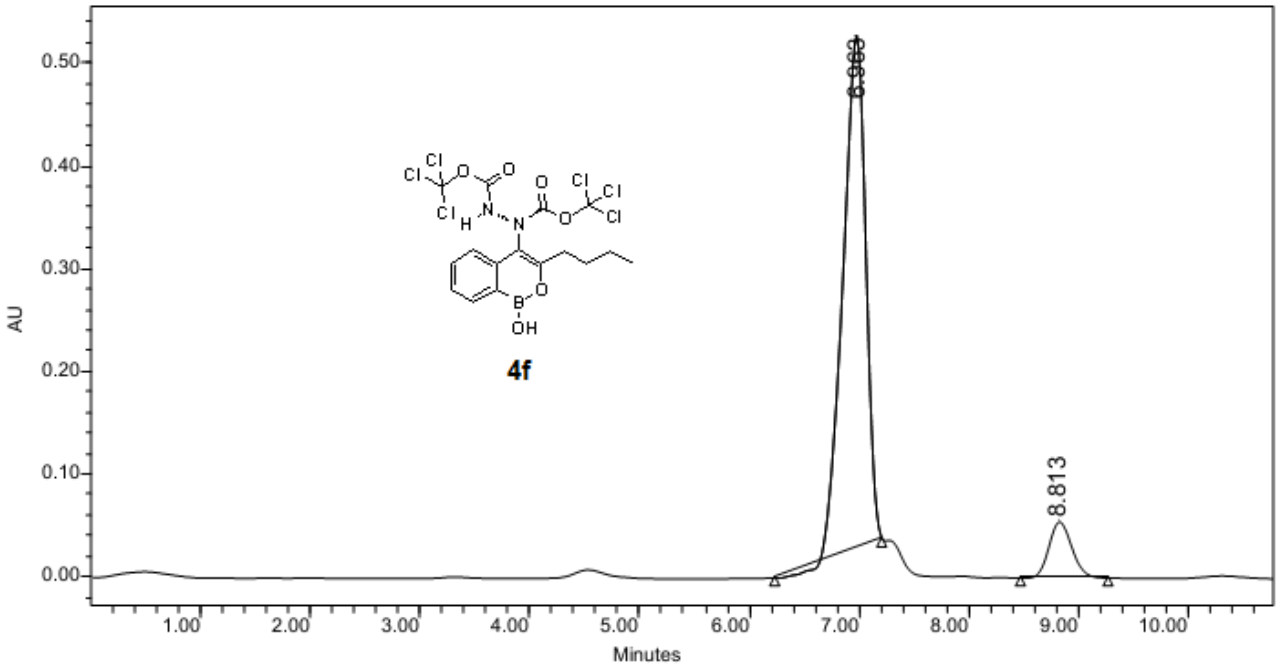


	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.358	5502549	90.62	423147	91.85
2	6.504	569841	9.38	37562	8.15



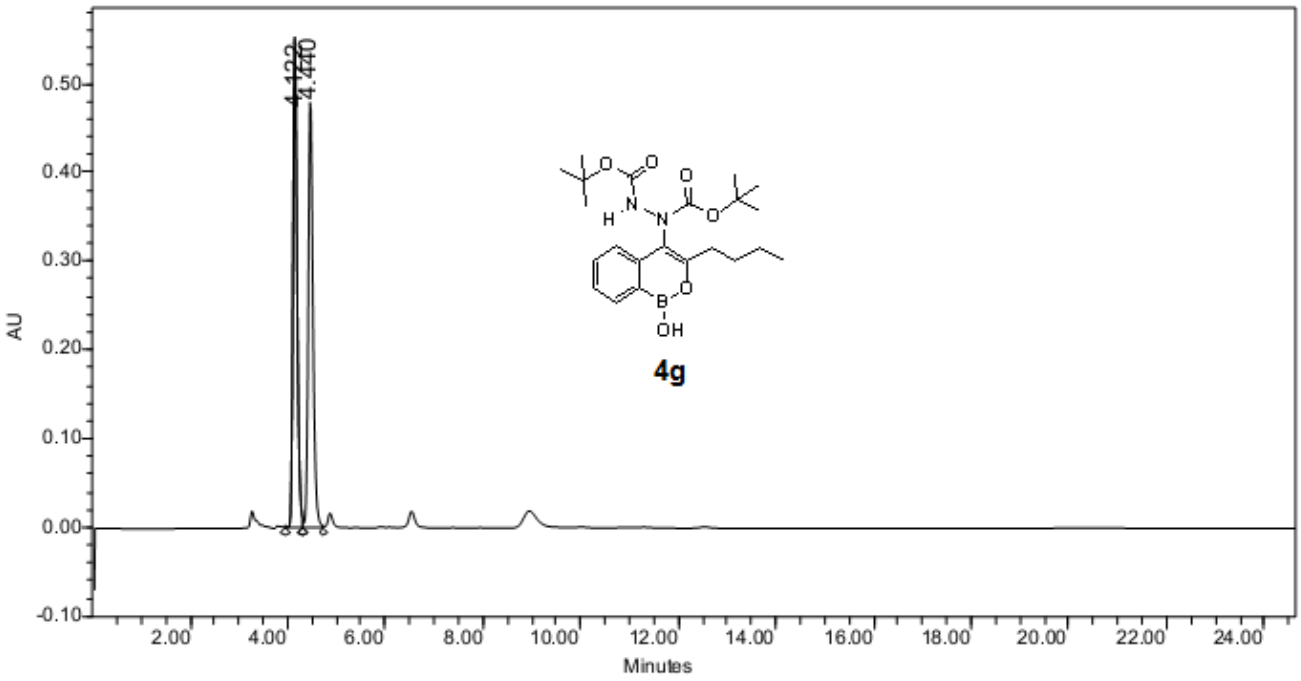
4f

	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	6.950	20806485	50.48	1124608	45.45
2	8.689	20407507	49.52	1349624	54.55



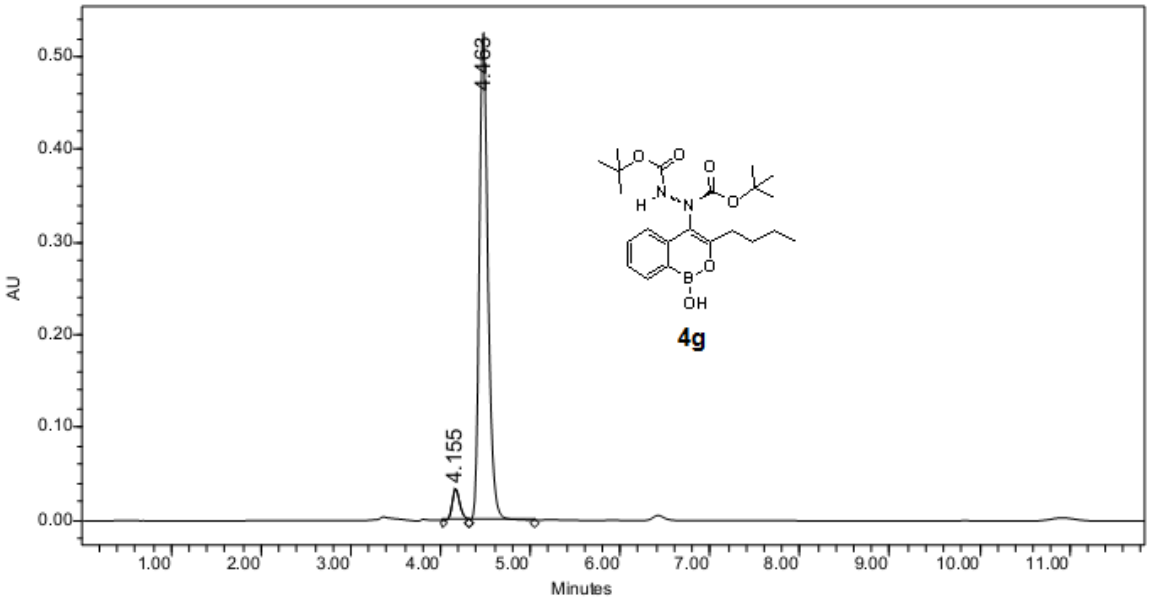
4f

	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	6.963	7306421	90.17	500082	90.13
2	8.813	796399	9.83	54763	9.87



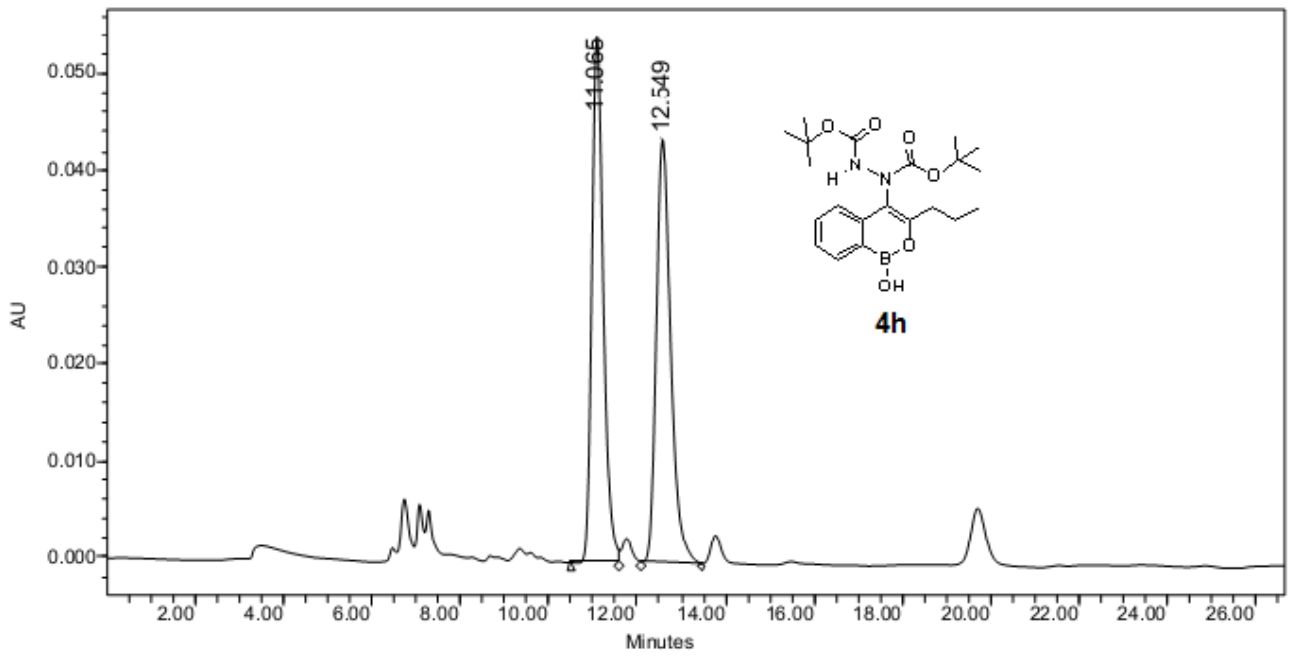
4g

	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.122	3242190	49.85	551010	53.34
2	4.440	3261733	50.15	482003	46.66

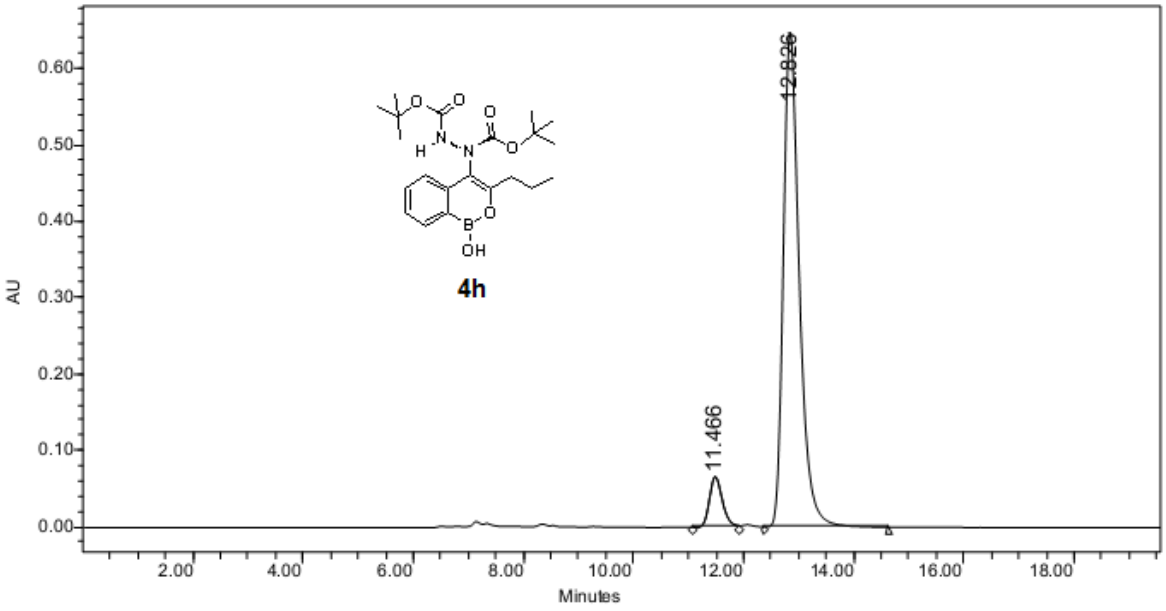


4g

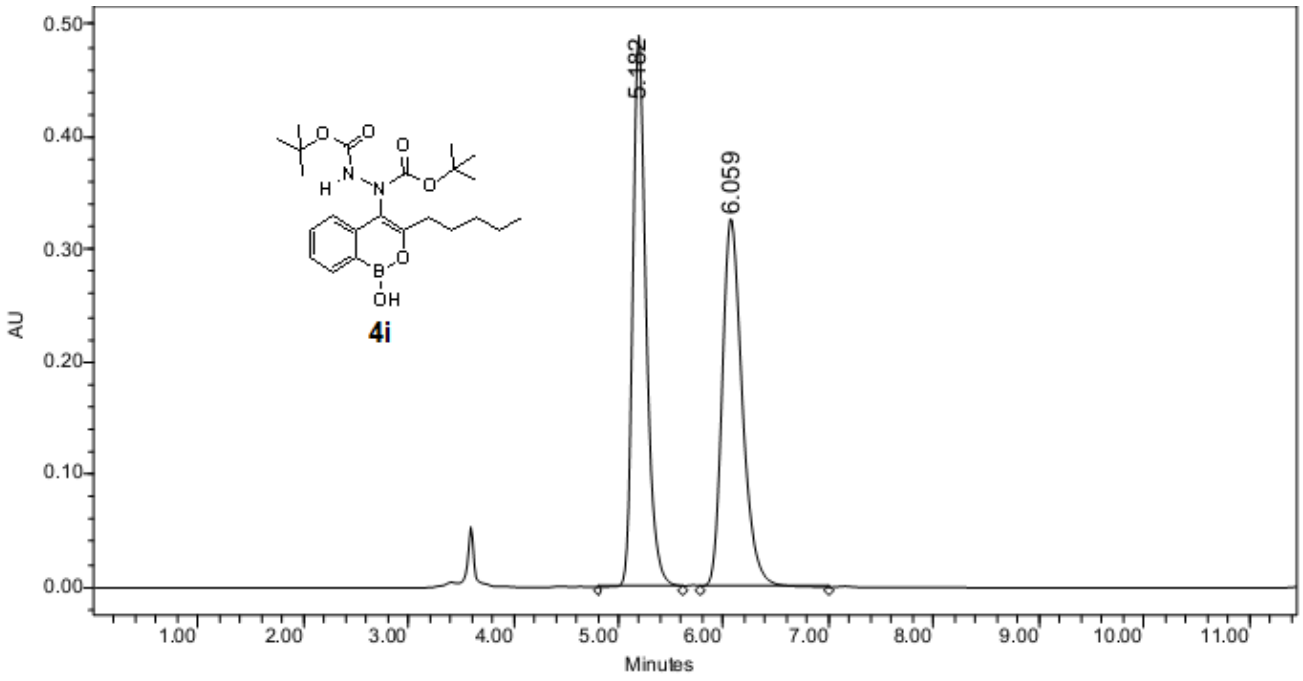
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.155	214458	5.67	34619	6.17
2	4.463	3564708	94.33	526082	93.83



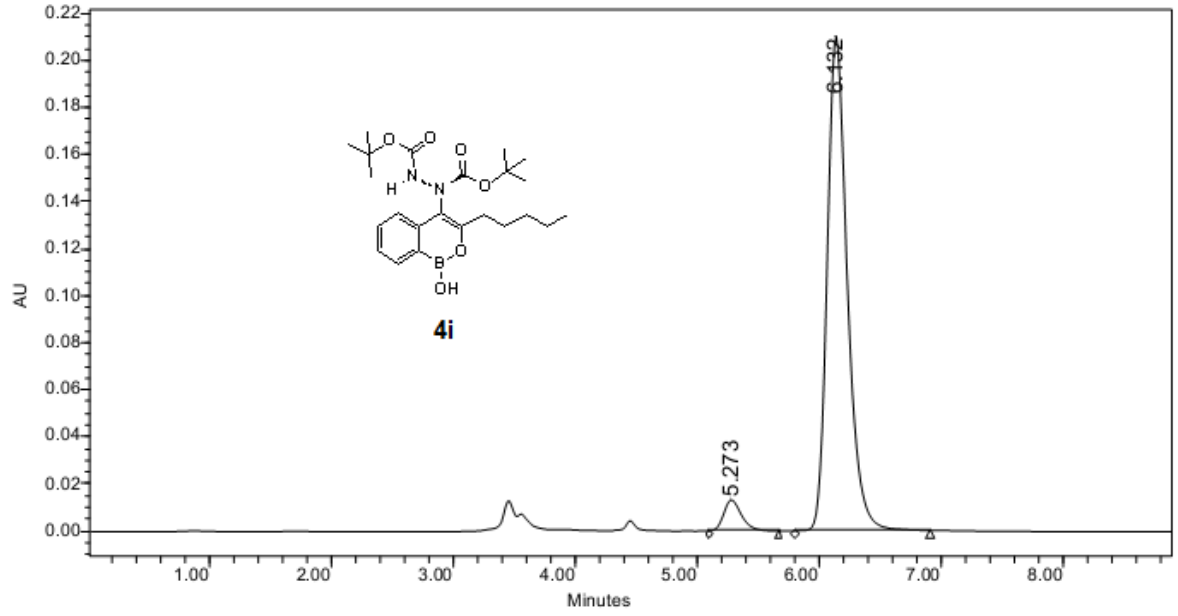
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	11.065	977112	49.54	54265	55.31
2	12.549	995182	50.46	43849	44.69



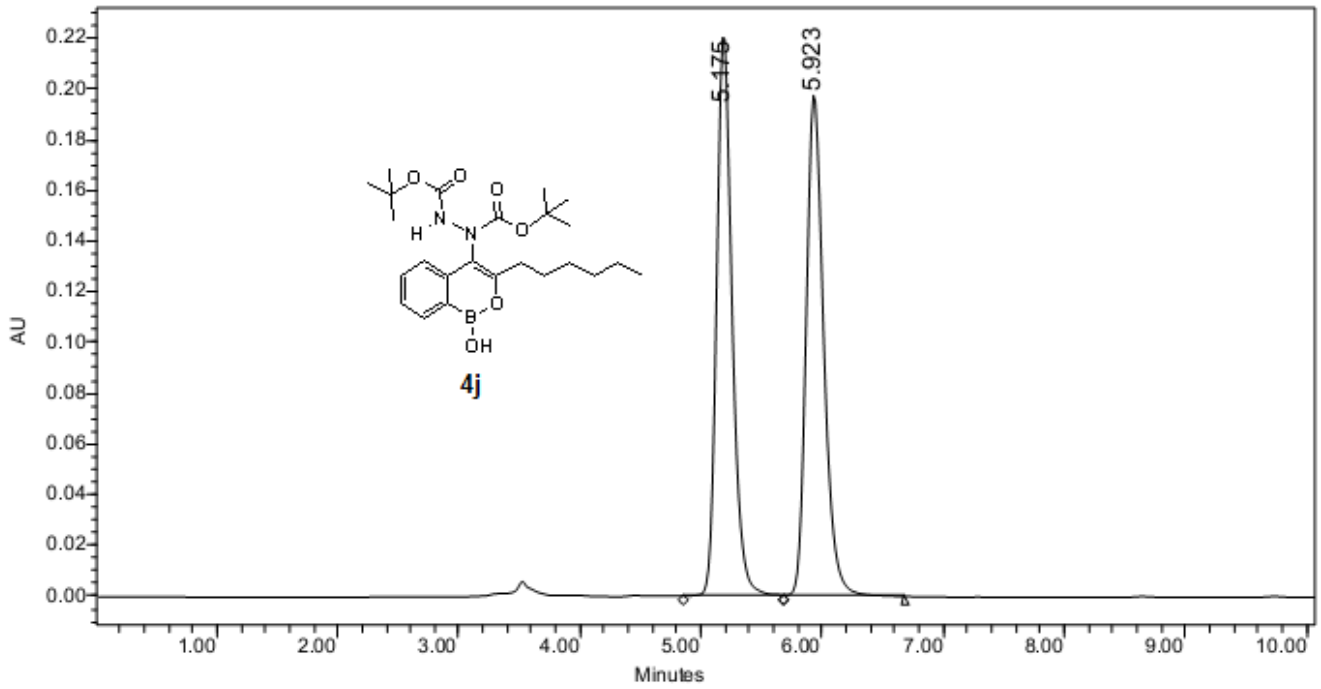
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	11.466	1106033	7.80	66588	9.30
2	12.826	13077830	92.20	649071	90.70



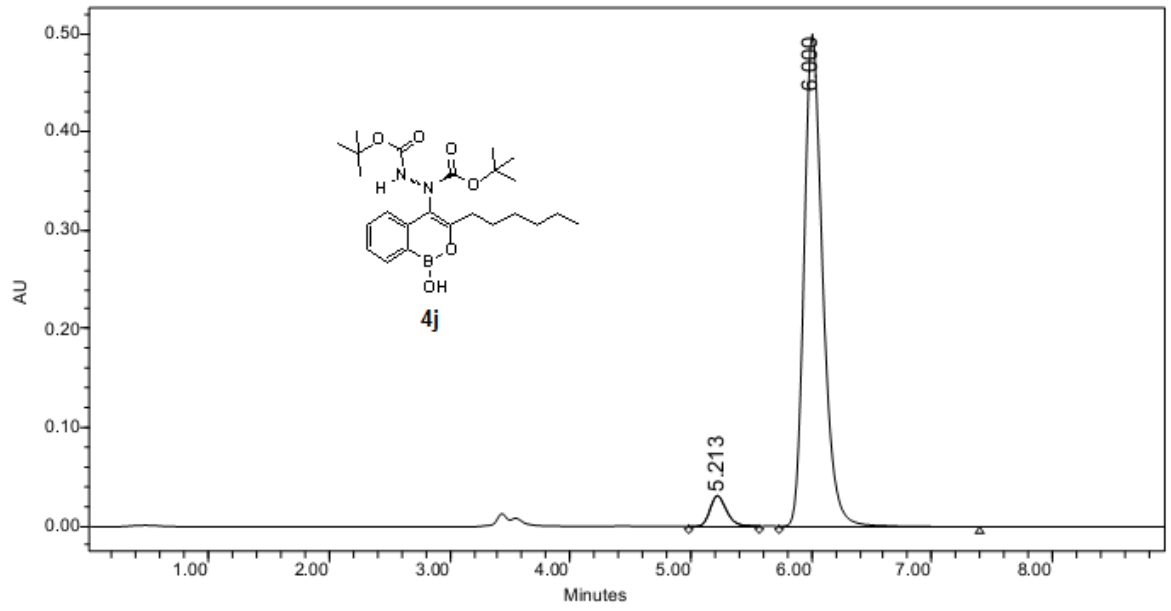
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.182	4360759	49.93	489661	59.90
2	6.059	4373183	50.07	327745	40.10



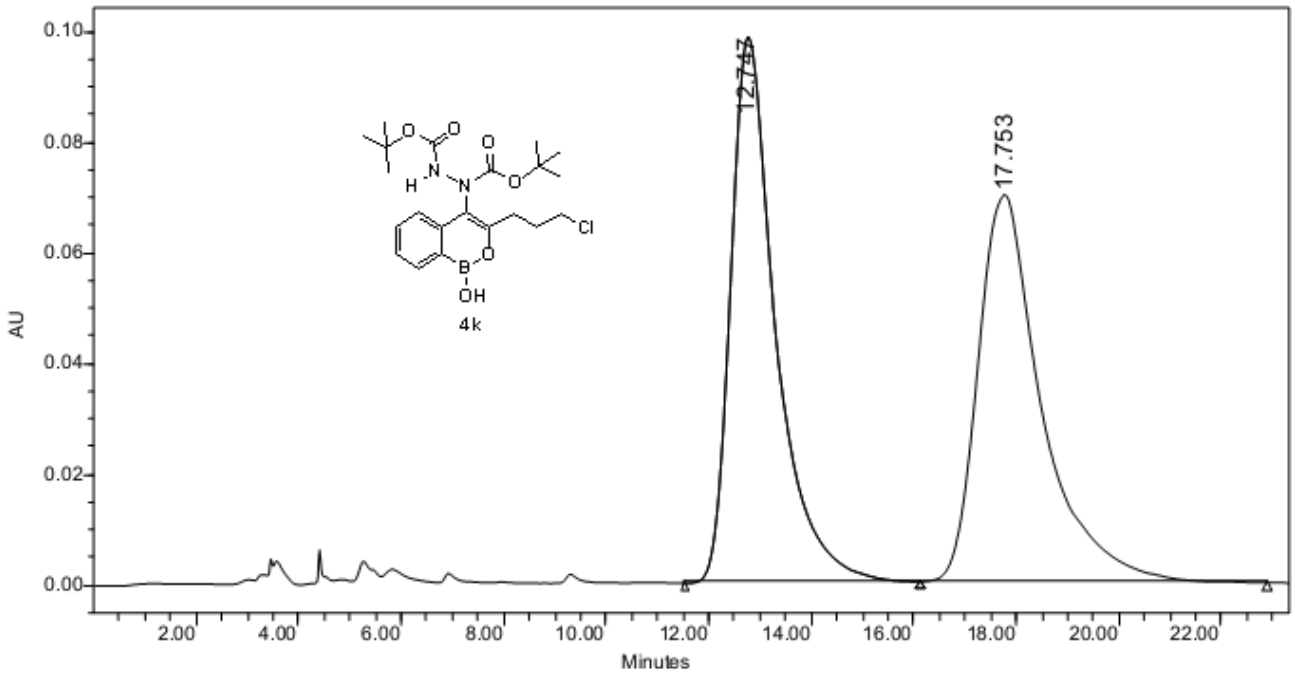
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.273	135426	5.32	13214	5.91
2	6.132	2411703	94.68	210277	94.09



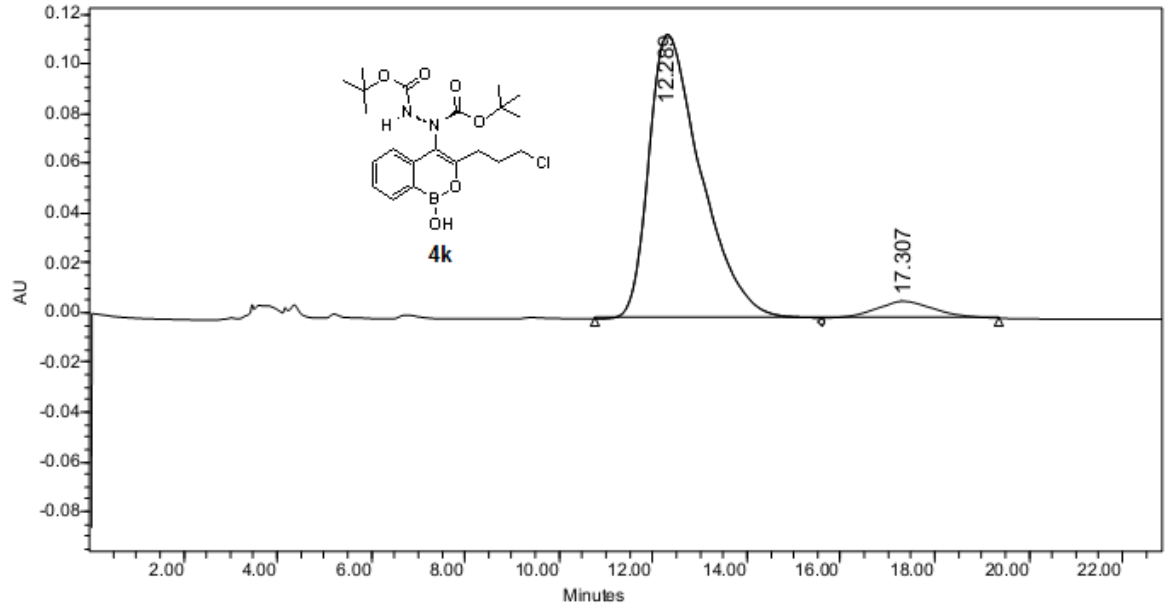
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.175	1989661	49.84	222424	52.86
2	5.923	2002287	50.16	198373	47.14



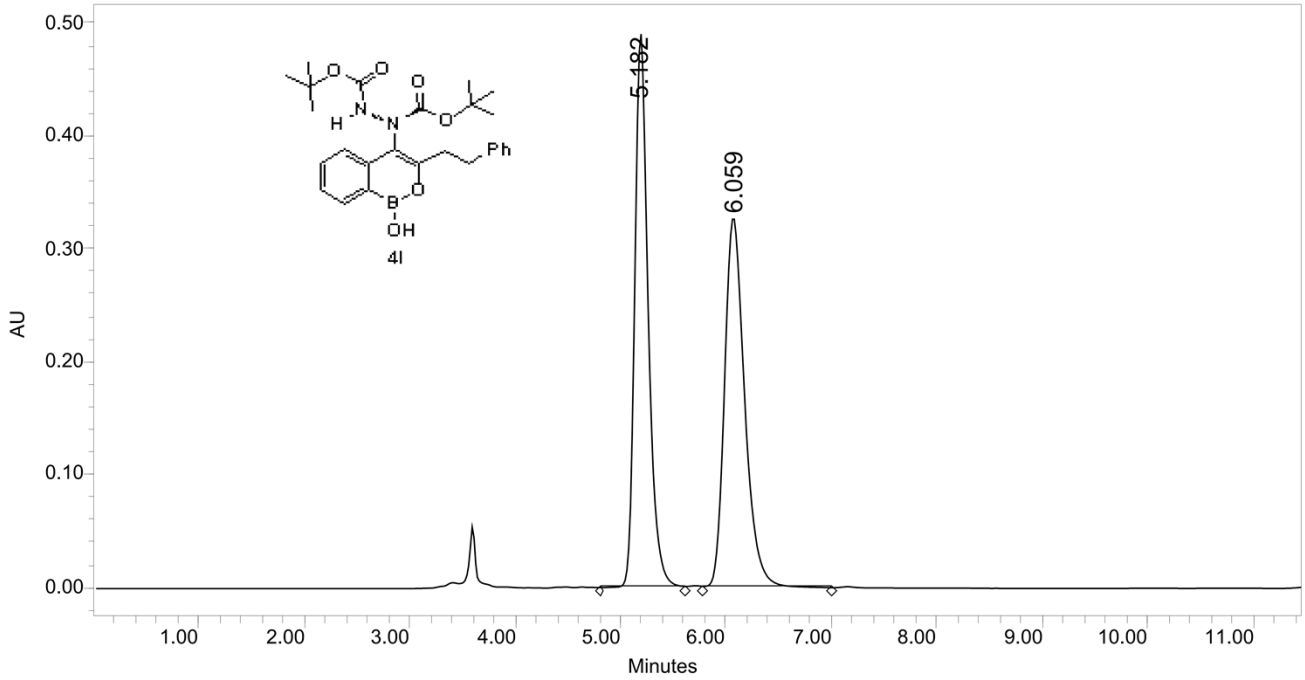
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.213	317969	5.56	31757	5.97
2	6.000	5401703	94.44	499824	94.03



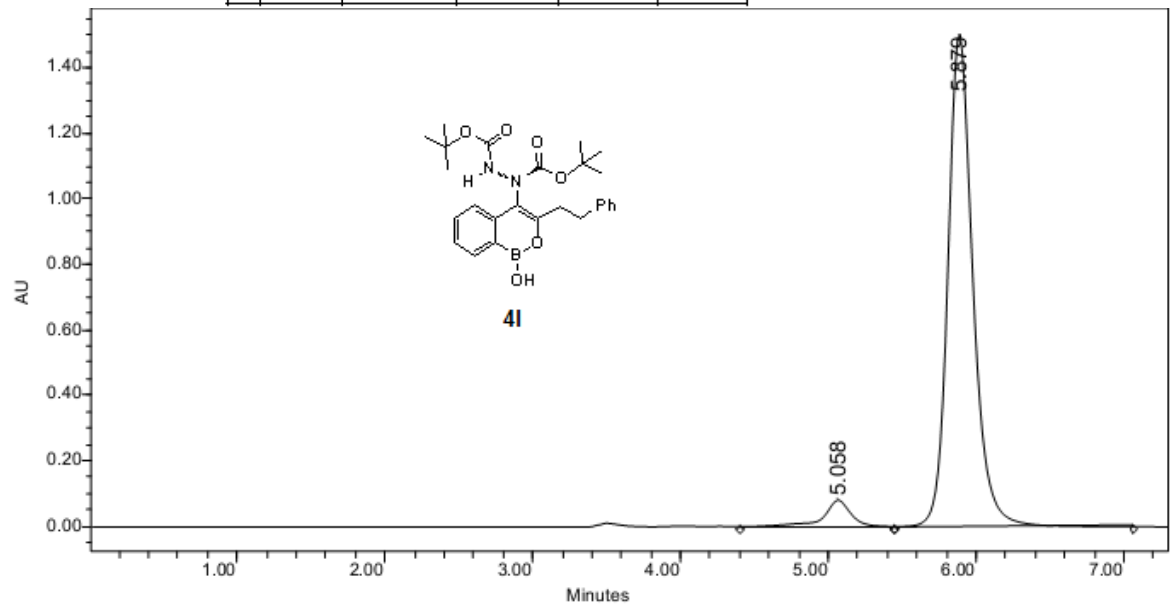
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	12.747	6000203	49.91	98589	58.51
2	17.753	6022753	50.09	69903	41.49



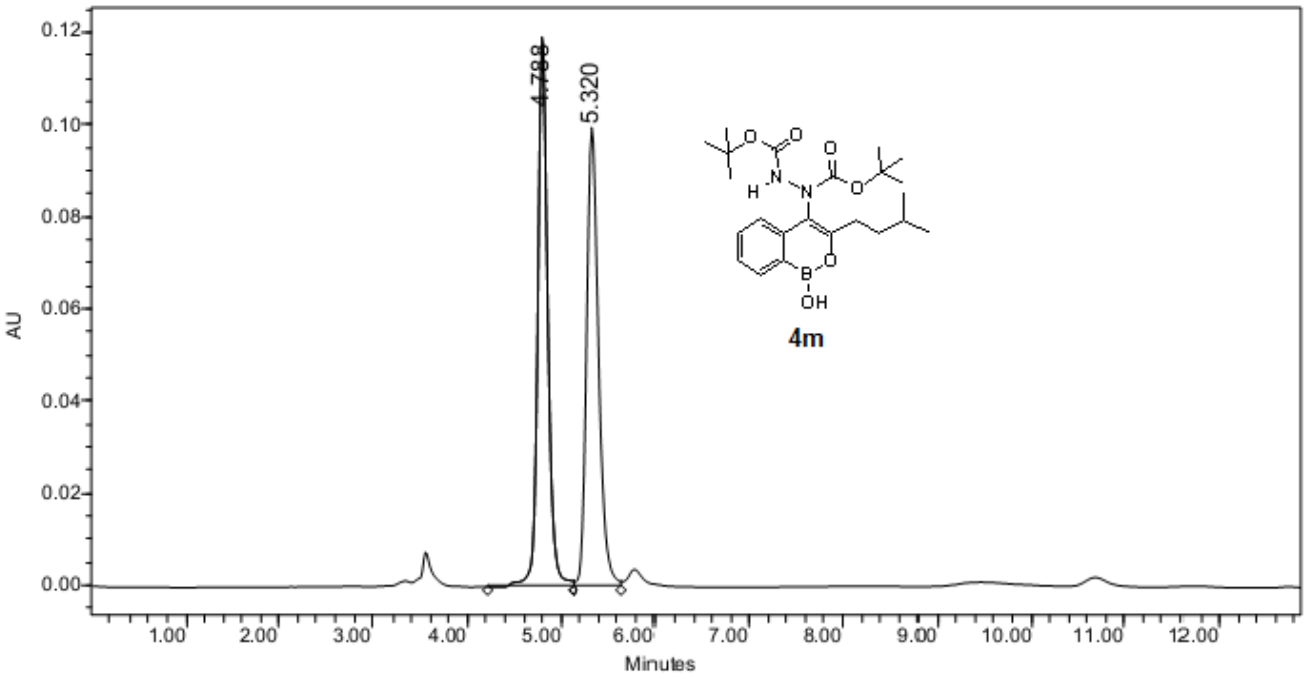
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	12.289	8839551	93.52	114118	94.34
2	17.307	612358	6.48	6850	5.66



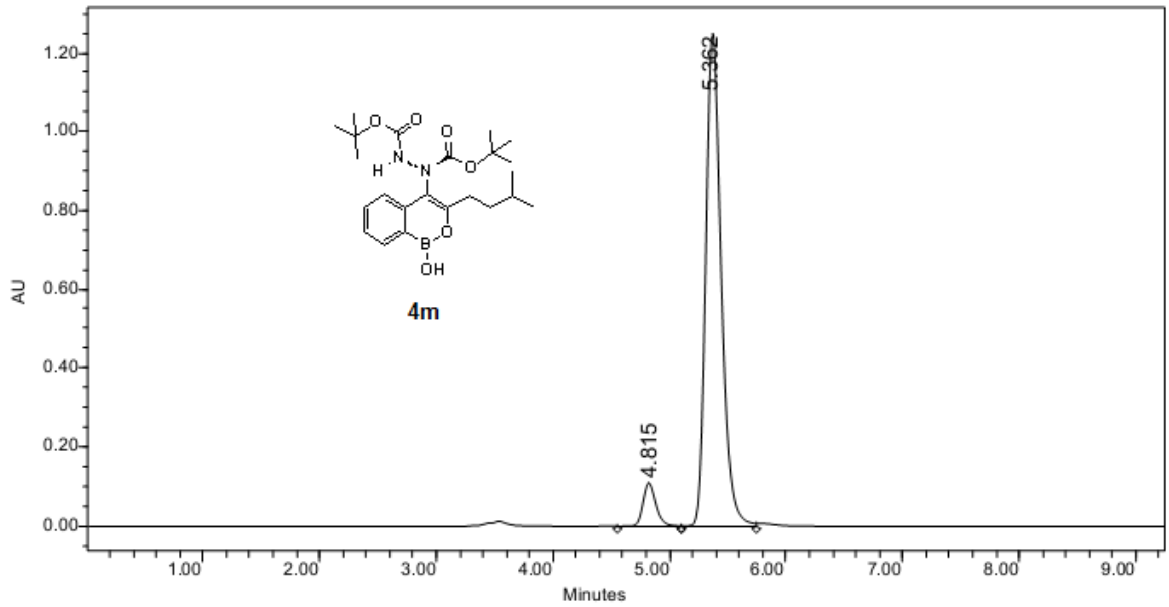
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.182	4360759	49.93	489661	59.90
2	6.059	4373183	50.07	327745	40.10



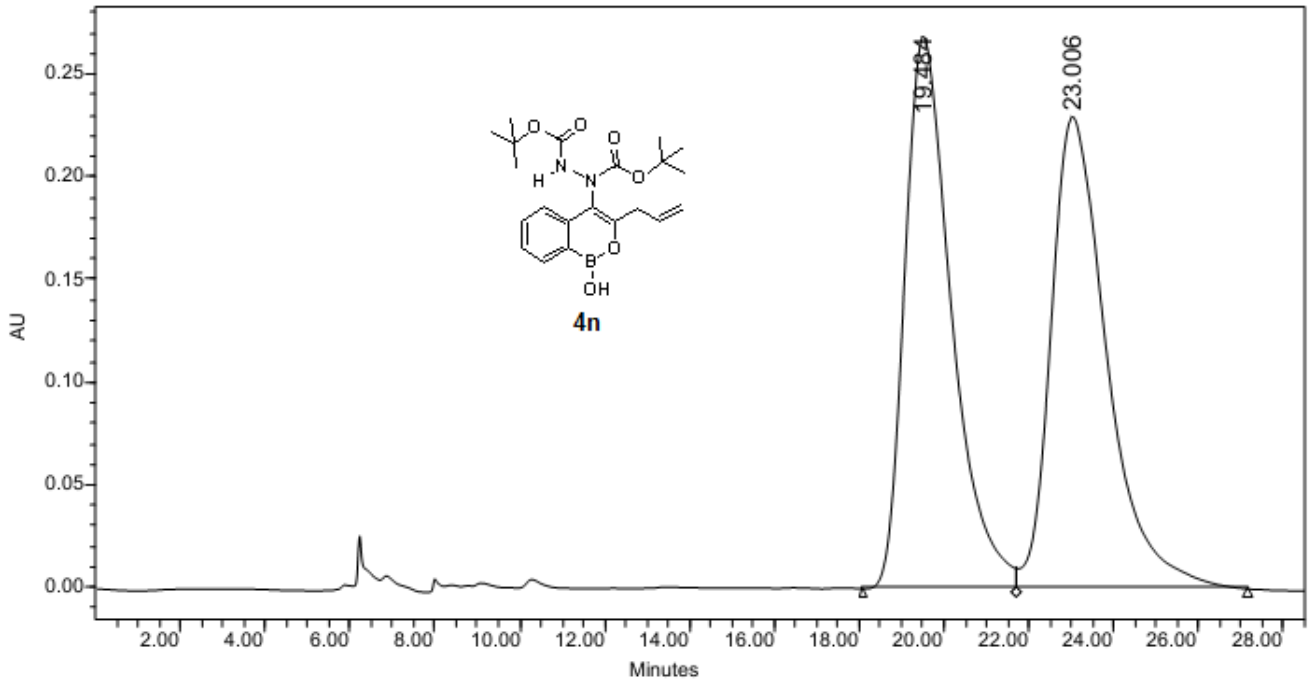
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.058	1144407	6.05	82109	5.17
2	5.879	17768363	93.95	1507096	94.83



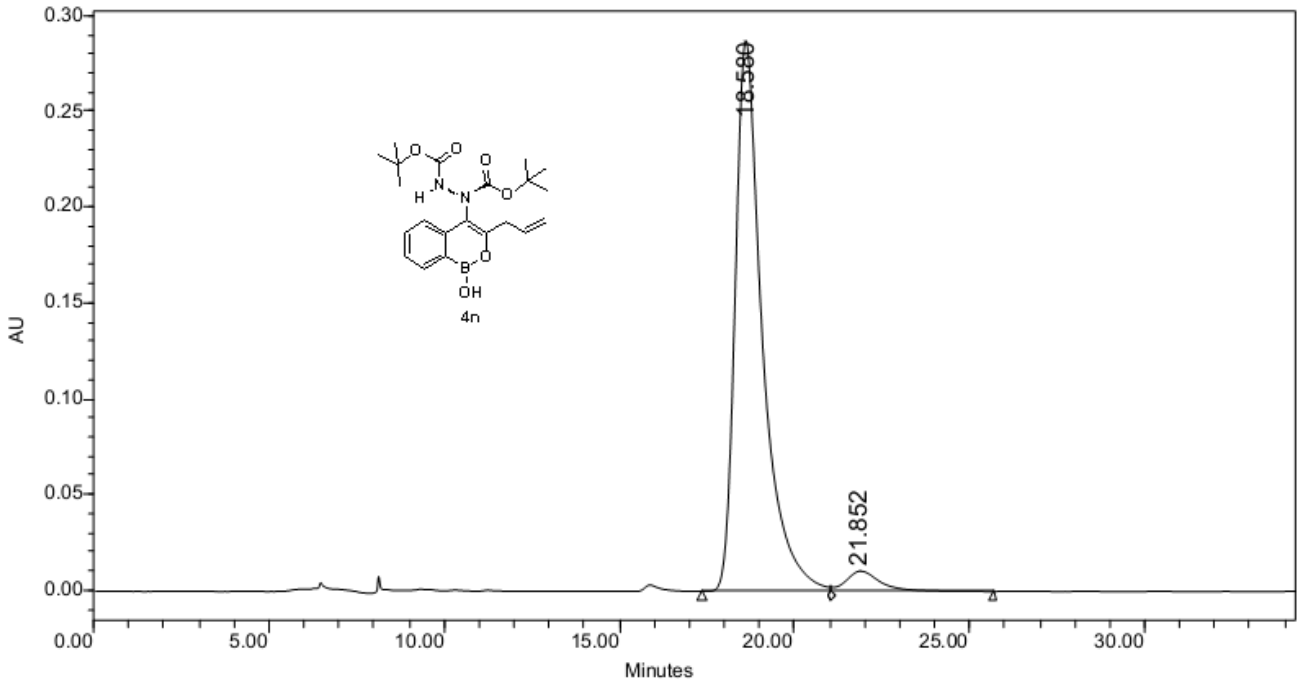
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.788	900677	50.26	119422	54.50
2	5.320	891382	49.74	99706	45.50



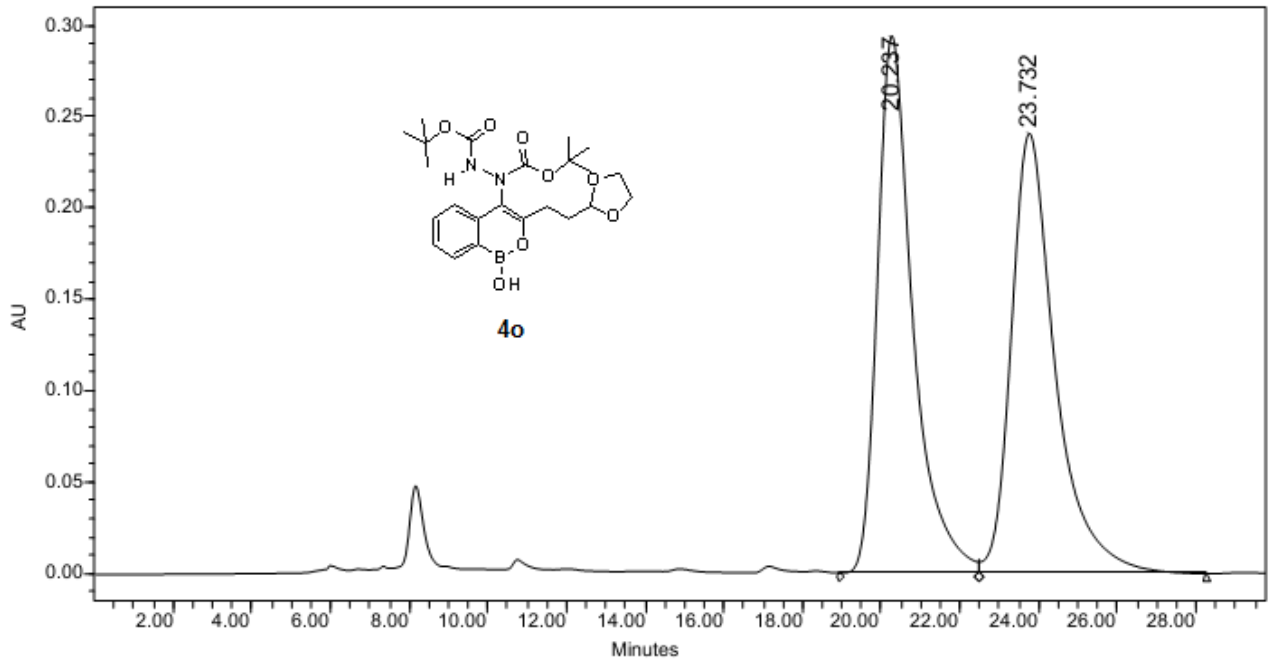
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.815	870709	7.00	110488	8.11
2	5.362	11559728	93.00	1252601	91.89



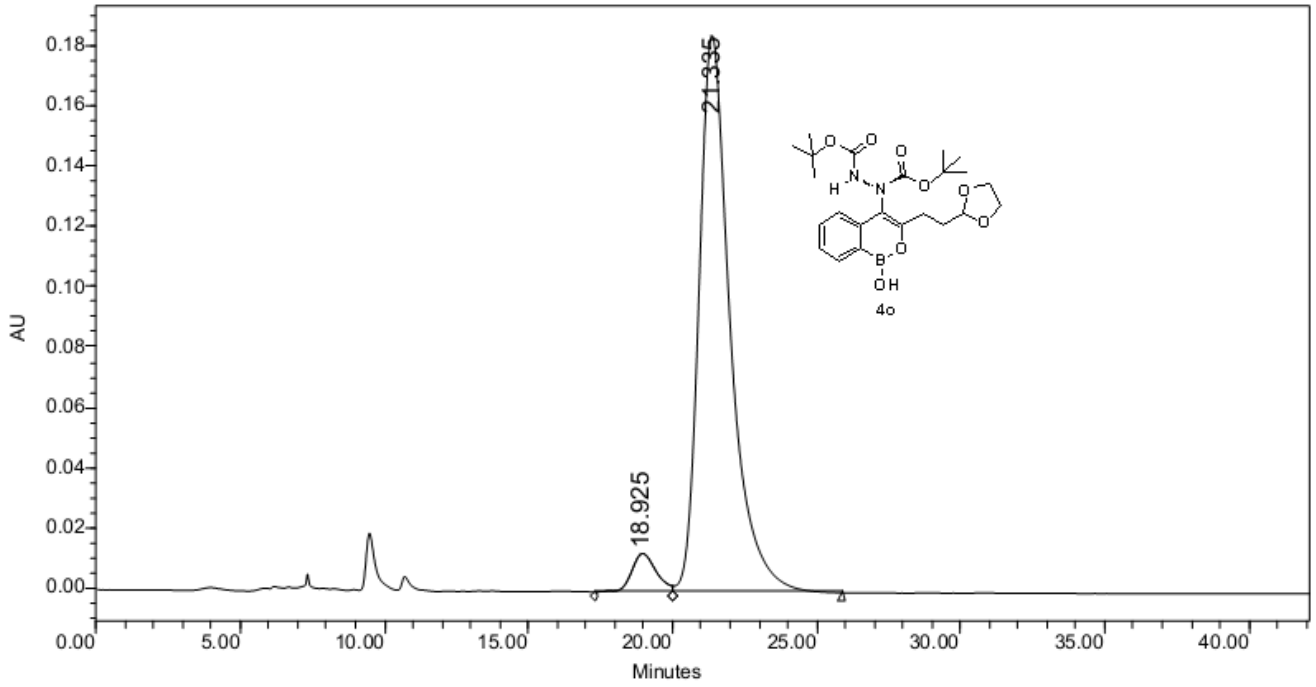
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	19.484	20630443	49.48	268886	53.91
2	23.006	21061367	50.52	229849	46.09



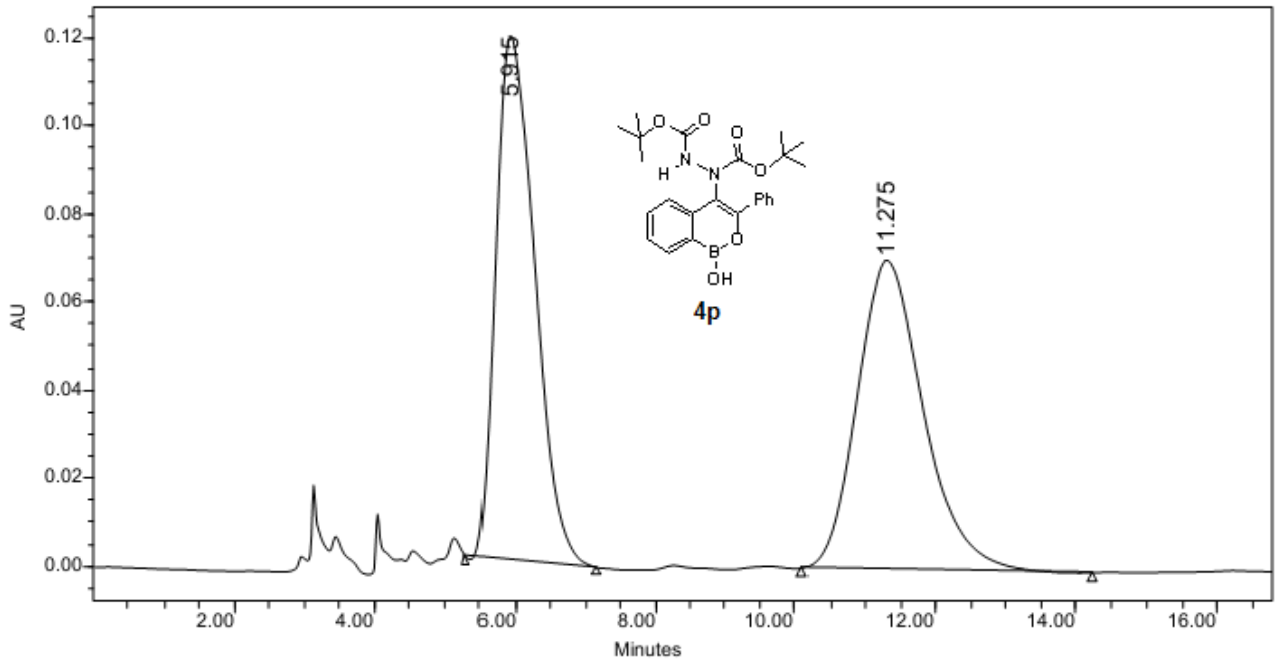
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	18.580	15534390	95.50	287573	96.44
2	21.852	732434	4.50	10627	3.56



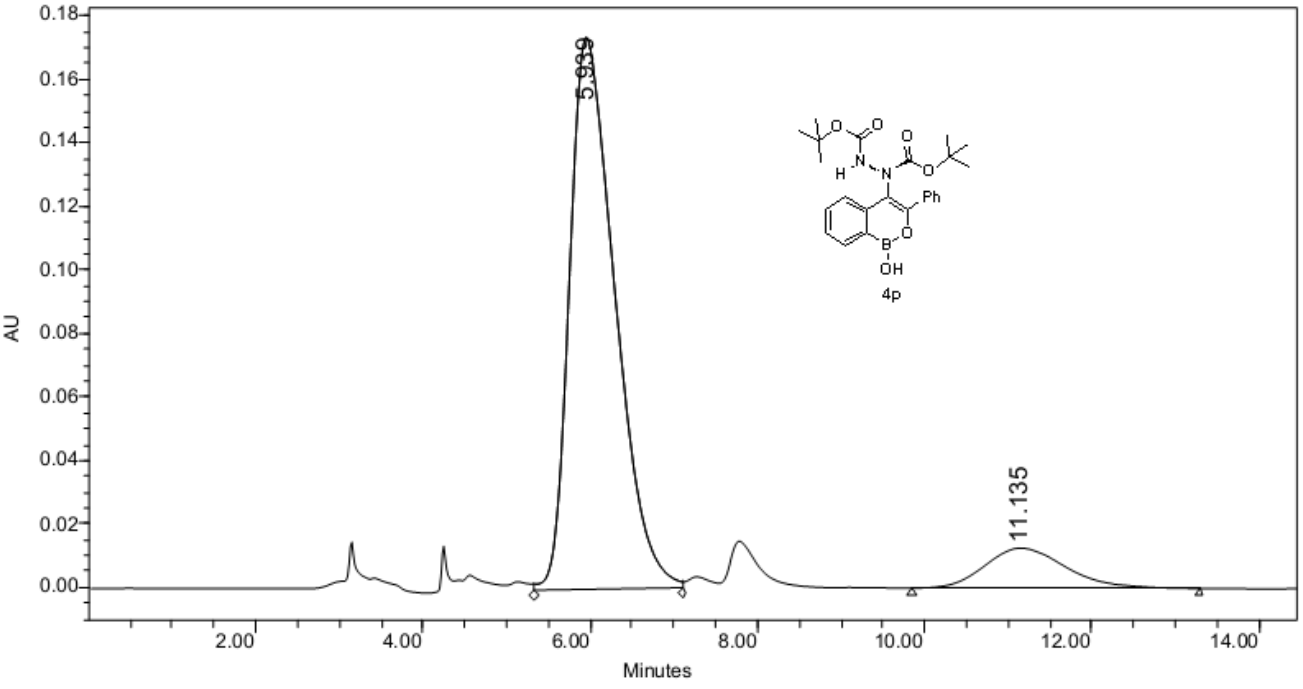
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	20.237	18452912	49.63	294226	54.98
2	23.732	18729274	50.37	240909	45.02



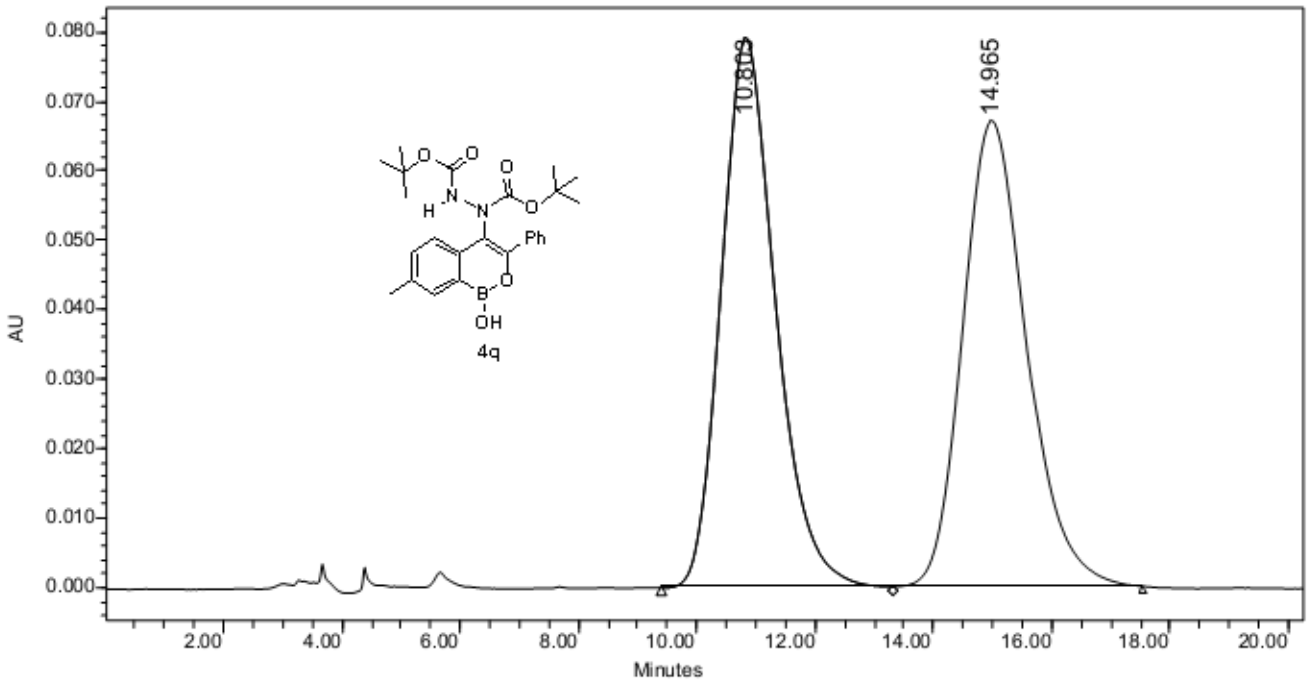
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	18.925	769005	5.23	12756	6.47
2	21.335	13921426	94.77	184455	93.53



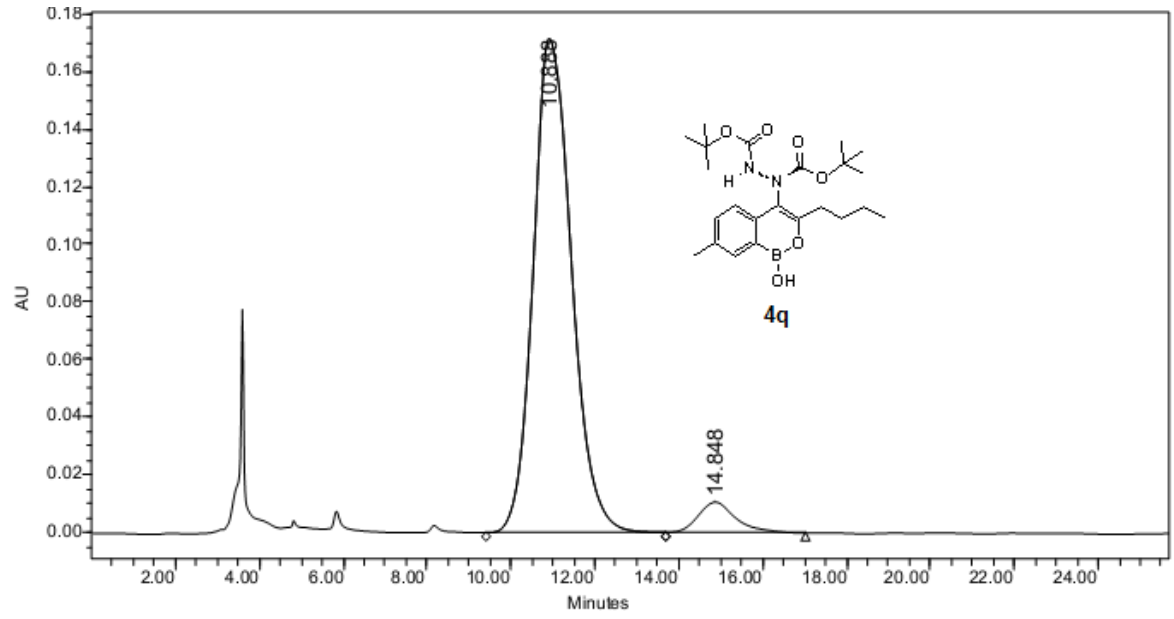
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.915	4588828	49.82	119090	62.93
2	11.275	4622201	50.18	70145	37.07



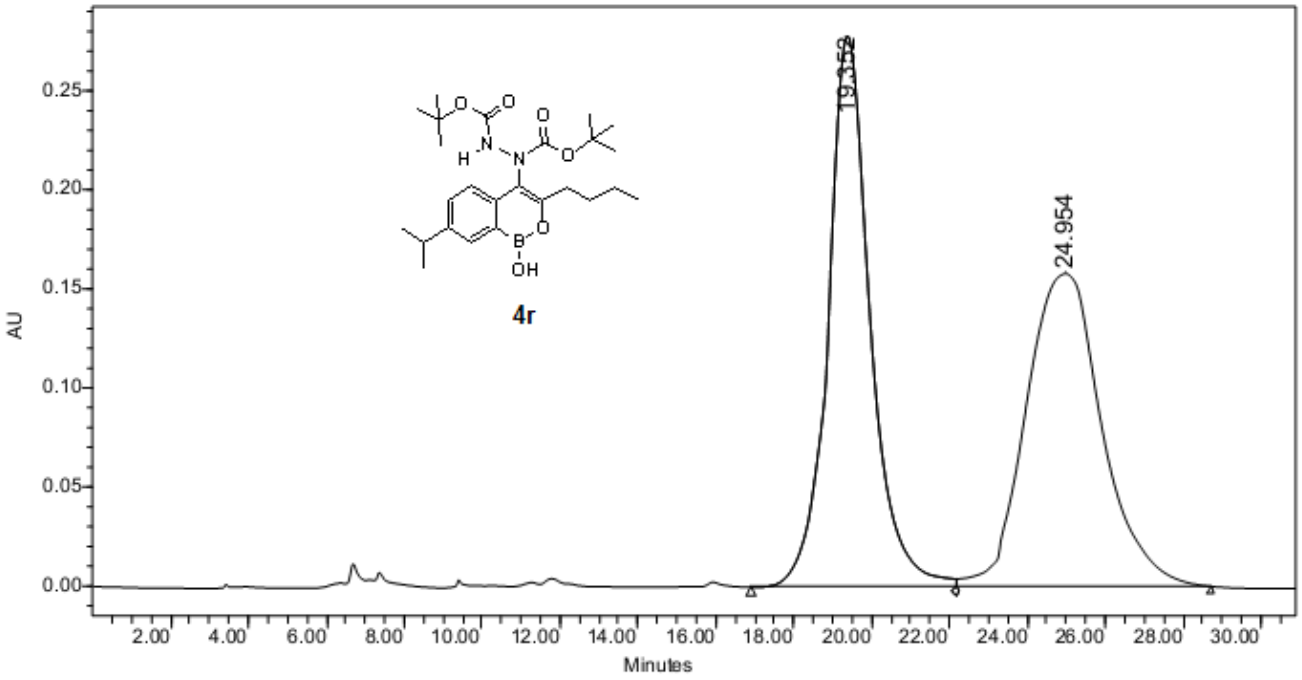
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.939	6607057	88.56	174354	93.25
2	11.135	853332	11.44	12630	6.75



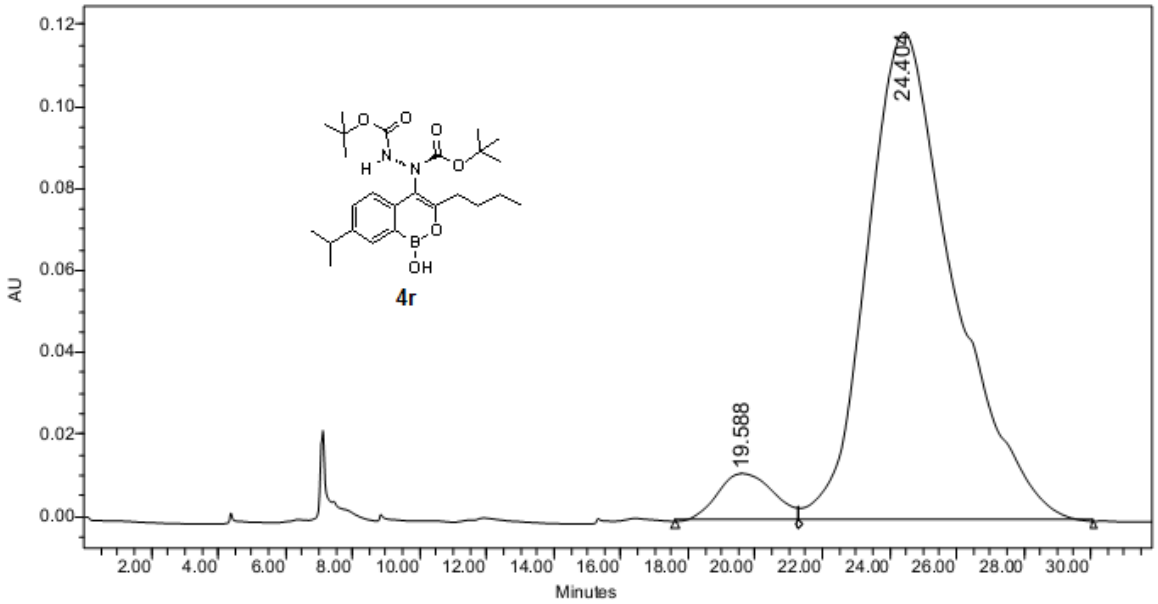
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	10.803	5042188	50.05	79099	54.12
2	14.965	5032802	49.95	67048	45.88



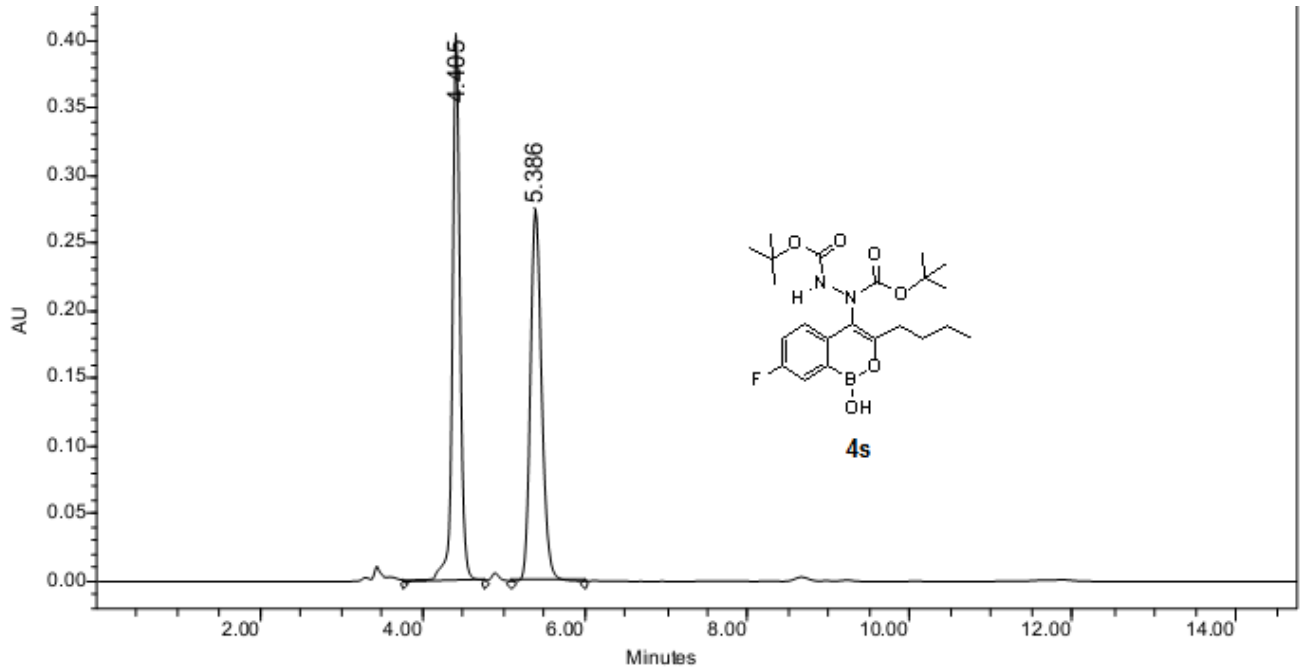
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	10.888	10981667	94.09	171822	94.11
2	14.848	689264	5.91	10761	5.89



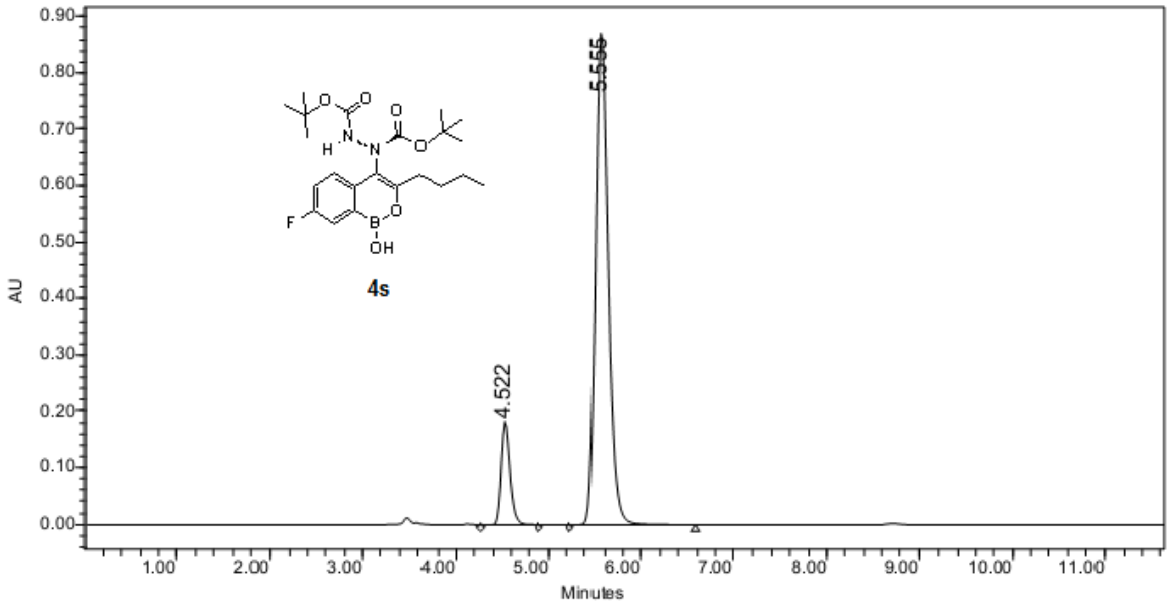
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	19.352	20879250	49.39	277865	63.75
2	24.954	21396169	50.61	157977	36.25



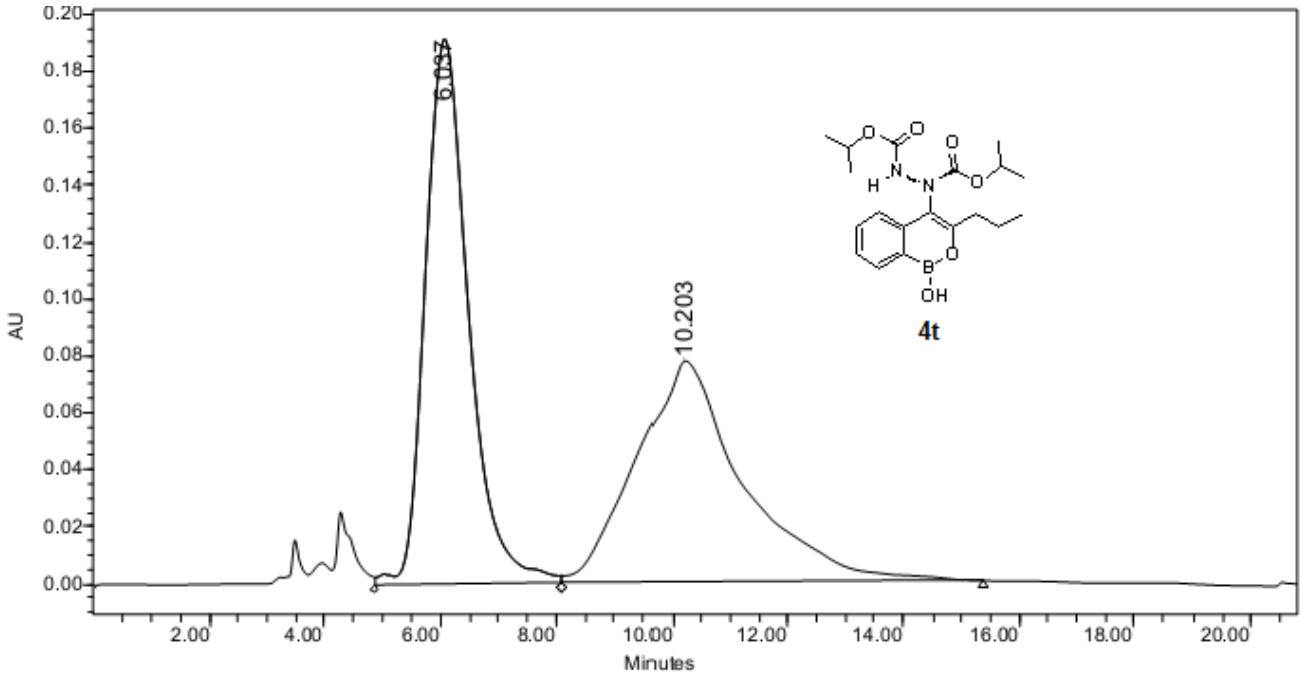
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	19.588	1384602	6.07	11657	8.90
2	24.404	21408877	93.93	119302	91.10



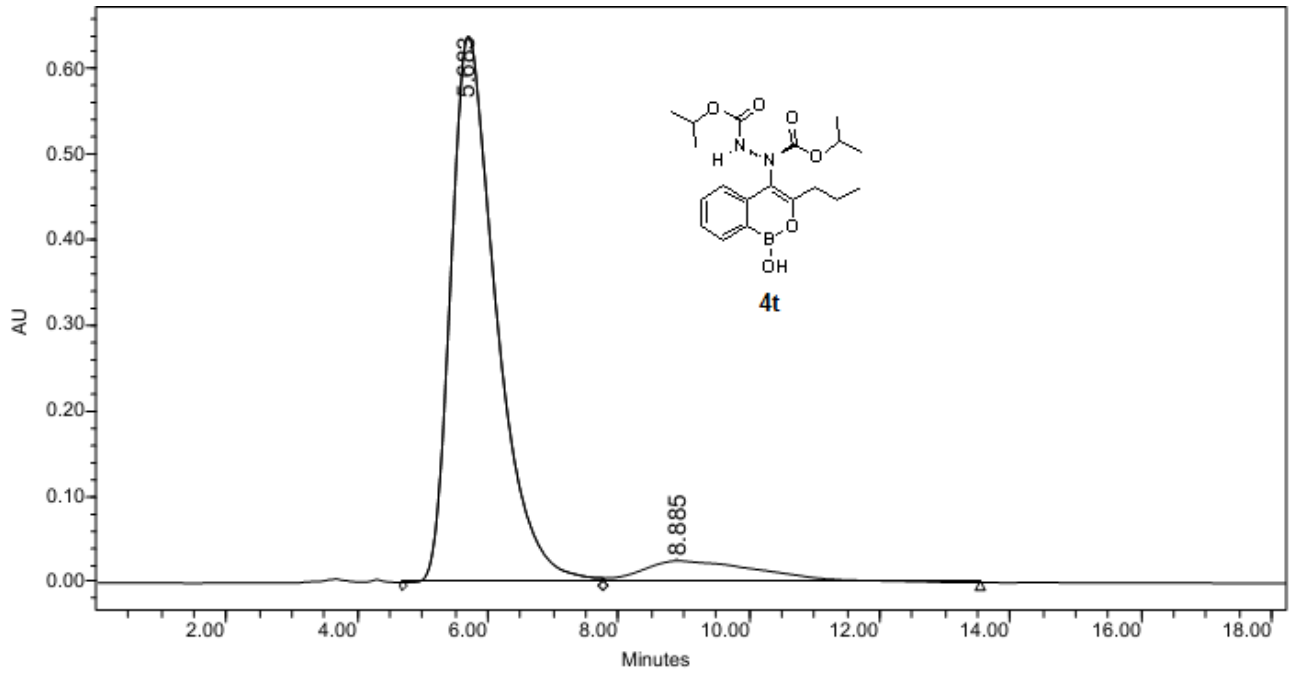
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.405	2661615	49.93	404708	59.45
2	5.386	2669210	50.07	276078	40.55



	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	4.522	1241910	13.19	182337	17.28
2	5.555	8176560	86.81	872834	82.72



	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	6.037	10105003	50.29	191715	71.06
2	10.203	9988692	49.71	78072	28.94



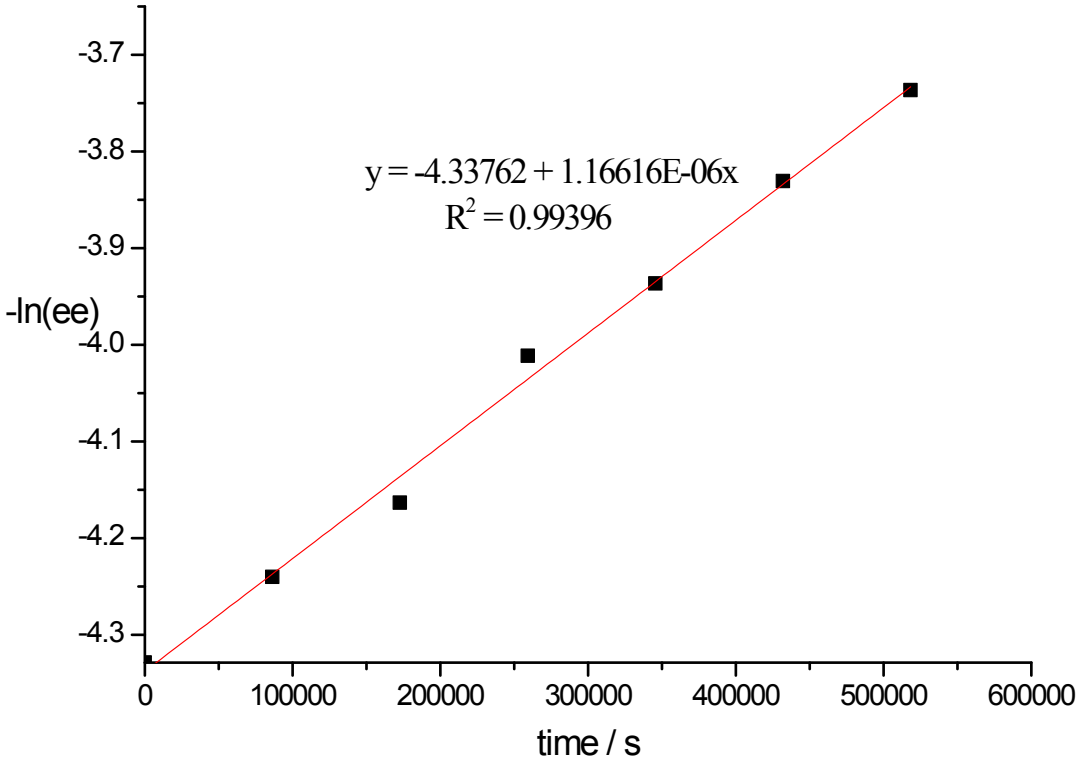
	RT (min)	Area (V*sec)	% Area	Height (V)	% Height
1	5.683	31069322	90.03	640131	96.13
2	8.885	3440994	9.97	25749	3.87

Part IV Barriers to racemization of 4g

Fractions collected and racemised by incubation at 40 °C in 5:1 PE:EtOAc

time/s	ee(%)	-ln(ee)
0	75.84	-4.32863
86400	69.42	-4.24018
172800	64.28	-4.16325
345600	55.22	-4.01133
432000	51.24	-3.93652
518400	46.10	-3.83081
604800	41.96	-3.73672

Exponential decay:

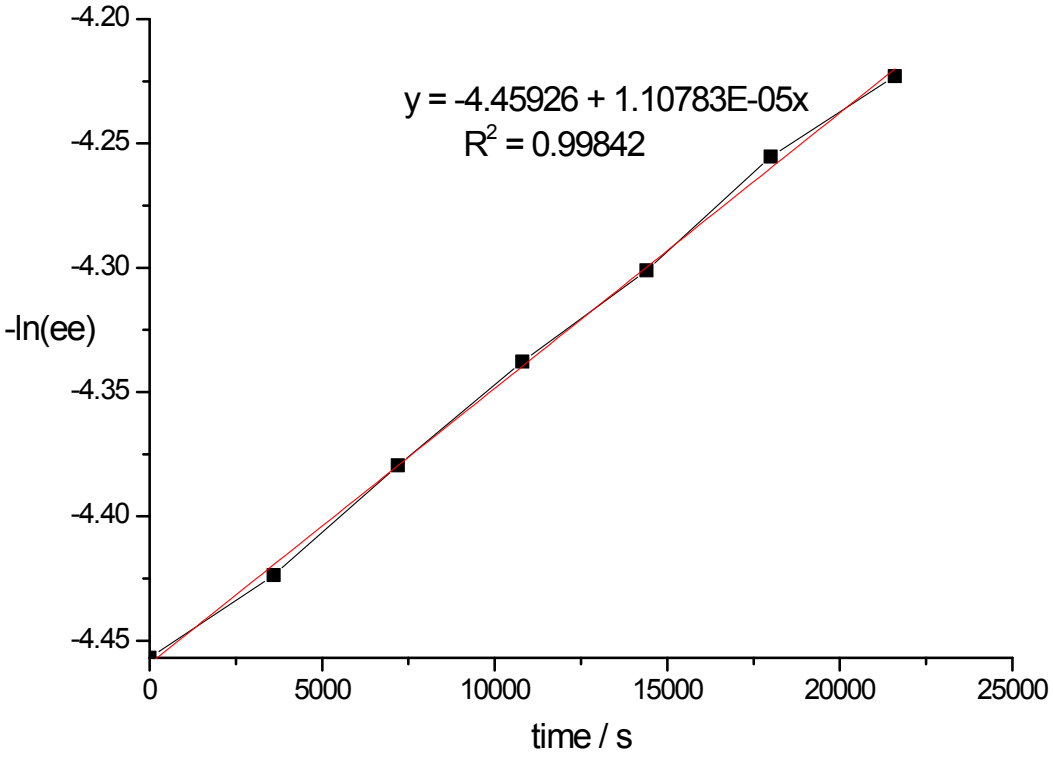


Half - life at 40 °C = 163.8 h

Fractions collected and racemised by incubation at 60 °C in 5:1 PE:EtOAc

time/s	ee(%)	-ln(ee)
0	86.22	-4.4569
3600	83.40	-4.42365
7200	79.80	-4.37952
10800	76.54	-4.33781
14400	73.78	-4.30109
18000	70.48	-4.25533
21600	68.24	-4.22303

Exponential decay:

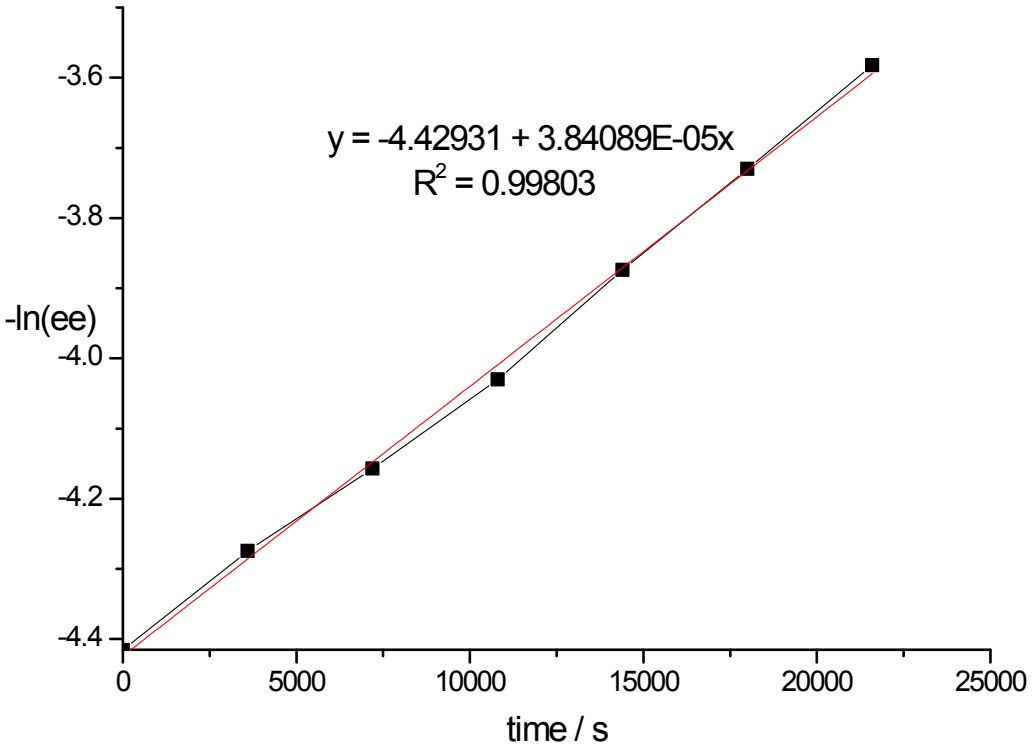


Half - life at 60 °C = 17.3 h

Fractions collected and racemized by incubation at 80 °C in 5:1 PE:EtOAc

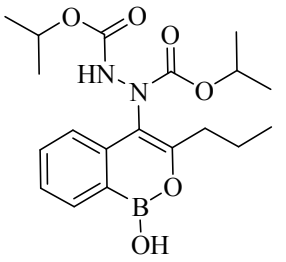
time/s	ee(%)	-ln(ee)
0	82.74	-4.41570
3600	71.84	-4.27444
7200	63.88	-4.15701
10800	56.26	-4.02998
14400	48.14	-3.87411
18000	41.68	-3.73002
21600	35.96	-3.58241

Exponential decay:



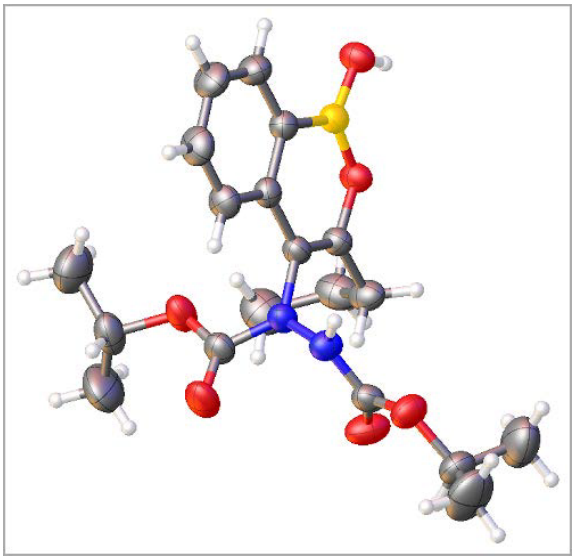
Half - life at 60 °C =5.0 h

Part V Crystal data and structure refinement for 4t



4t

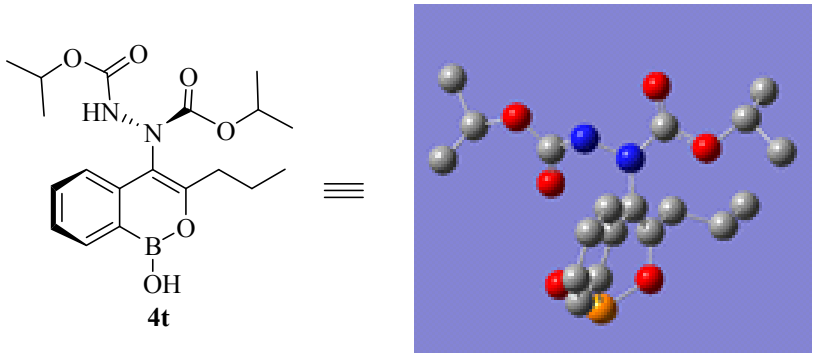
≡



4t

Identification code	gr130224
Empirical formula	$C_{19}H_{27}BN_2O_6$
Formula weight	390.24
Temperature/K	290(2)
Crystal system	triclinic
Space group	P-1
a/Å	9.8024(4)
b/Å	10.2502(3)
c/Å	11.0769(3)
α/°	91.745(2)
β/°	108.985(3)
γ/°	92.310(3)
Volume/Å^3	1050.45(6)
Z	2
ρ_{calc}mg/mm^3	1.234
m/mm ^{1}	0.750
F(000)	416.0
Crystal size/mm^3	0.36 × 0.32 × 0.27
2Θ range for data collection	9.56 to 139.68°
Index ranges	$-10 \le h \le 11$, $-12 \le k \le 12$, $-13 \le l \le 13$
Reflections collected	17227
Independent reflections	3896[R(int) = 0.0233]
Data/restraints/parameters	3896/1/258
Goodness-of-fit on F^2	1.045
Final R indexes[I>=2σ (I)]	R_1 = 0.0448, wR_2 = 0.1269
Final R indexes [all data]	R_1 = 0.0469, wR_2 = 0.1295
Largest diff. peak/hole / e Å^{-3}	0.41/-0.26

Part VI VCD for the absolute configuration determination of 4t



4t

Fig. S1 The 3D structure (left) and its most stable conformation (right) at the B3LYP/6-31G(d) level in the gas phase (H atoms are hidden for clarity).

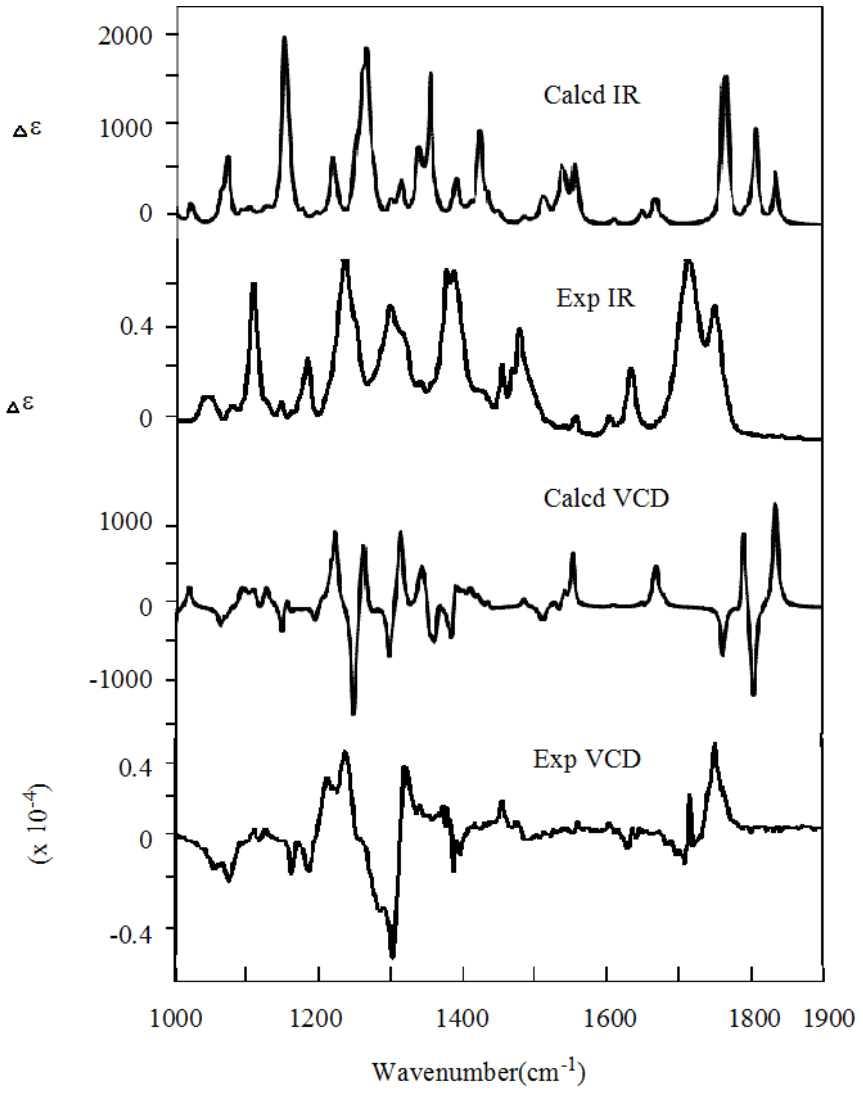


Fig. S2 The predicted VCD and IR curves and the experimental VCD and IR.

The conformational search using MMFF94F force field was performed for it and totally 184 geometries were found. Further optimization was carried out for the geometries with the same absolute configurations at the B3LYP/6-31G (d) level in the gas phase.[5] Then the B3LYP/6-31G (d)-optimized conformations were used for VCD calculations at the same level.[6,7] The lowest energy conformer is illustrated in Fig. S2 (for clarity, the H atoms are hidden). The simulated VCD and experimental VCD are illustrated in Fig. S3. It is found that the two VCD curves matched well and therefore, the absolute configuration of **4t** should be *S* (Fig. S2). A hydrogen bond between the hydroxyl and the carbonyl groups somehow contributed to the chirality of **4t**.

Part VII References

1. C. Körner, P. Starkov and T. D. Sheppard., *J. Am. Chem. Soc.*, 2010, **132**, 5968.

2. R. R. Bard, J. F. Bunnett and R. P. Traber, *J. Org. Chem.*, 1979, **44**, 4918.

3. F. Menard, C. F. Weise and M. Lautens, *Org. Lett.*, 2007, **9**, 5365.

4. J. M. Herbert, *J. Labelled Cpd. Radiopharm.*, 1998, **41**, 859.

5. M. J. Frisch, G. W. Trucks, H. B. Schlegel, et al. *Gaussian 03 User's Reference* Gaussian Inc. 2003, Carnegie, PA. 15106, USA.

6 (a) N. Berova, P. L Polavarapu, K. Nakanish and R. W. Woody, *Comprehensive Chiroptical Spectrascopy* John Wiley & Sons, Hoboken, New Jersey, 2011; (b) P. J. Stephens, F. J. Devlin, J. R. Cheeseman, *VCD Spectroscopy for Organic Chemists* CRC Press, Taylor & Francis, 2012; (c) H.-J. Zhu, *Modern Organic Stereochemistry* Science Press, 2009.

7. (a) L. Nafie, *A. Nat. Prod. Commun.*, 2008, **3**, 451; (b) J. Ren, G.-L. Li, L. Shen, G.-L. Zhang, L. Nafie and H.-J. Zhu, *Tetrahedron*, 2013*,* **69***,* 10351.