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Electronic Supplementary Information

Total synthesis of tumor-associated KH-1 antigen core nonasaccharide via photo-induced glycosylation

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Contents

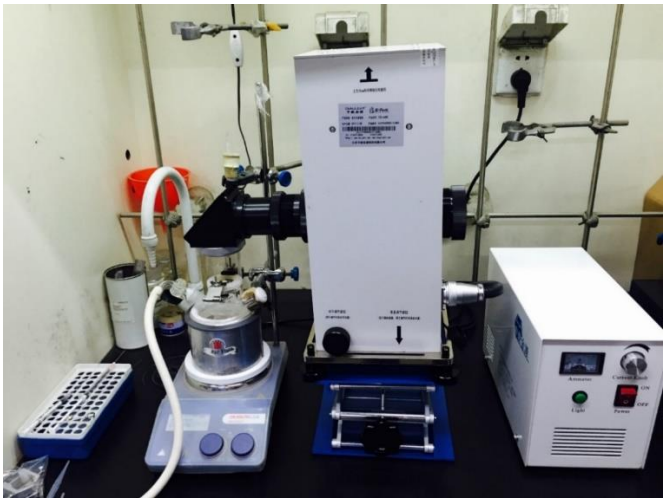
1. General Information

Reactions were carried out in oven-dried glassware. All chemicals were purchased as reagent grade and used without further purification, unless otherwise noted. All solvents were purified before use. CH_2Cl_2, CH_3CN, THF and pyridine were distilled over CaH_2. Methanol was distilled from magnesium. DMF was stirred with CaH_2 and distilled under reduced pressure. Toluene was distilled over sodium. All reactions were carried out under anhydrous conditions with freshly distilled solvents under a positive pressure of argon, unless otherwise noted. Umemoto's reagent refers to *S*-(trifluoromethyl)dibenzothiophenium tetrafluoroborate. Reactions were monitored by thin-layer chromatography (TLC) on silica gel-coated aluminum plates (60 F_{254}, E. Merck). Spots were visualized by UV light (254 nm) and charring with a solution of $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$ (24.00 g, 19.4 mmol) and $Ce(NH_4)_2(NO_3)_6$ (0.50 g, 0.9 mmol) in sulfuric acid (5%, 500 mL). Column chromatography was performed on silica gel (200—300 mesh). Gel filtration was performed on Sephadex LH-20 (Pharmacia). Optical rotations were obtained on a Hanon P850 Automatic Polarimeter. Experiments under UV irradiation were carried out using a safety and stable mercury lamp spotlight system purchased from Beijing Zhongjiao Jinyuan Technology Co., Ltd. (Item No. CEL-M500). ^{1}H NMR spectra were recorded at room temperature for solutions in $CDCl_3$ or D_2O with the Avance III-400 or III-600 instruments (Bruker), and the chemical shifts were referenced to the peak for TMS (0 ppm, $CDCl_3$) or external CH_3OH (3.34 ppm, D_2O). ^{13}C NMR spectra were recorded using the same NMR spectrometers and the chemical shifts were reported relative to internal $CDCl_3$ (δ = 77.16 ppm) or external CH_3OH (49.70 ppm, D_2O). Assignments of resonances in ^{1}H and ^{13}C NMR spectra were done using ^{1}H-^{1}H COSY, HSQC and HMBC experiments. The following standard abbreviations are used to indicate multiplicity: s = singlet, d = doublet, t = triplet, m = multiplet, dd = doublet of doublets, dt = doublet of triplets, td = triplet of doublets and br = broad. HRMS experiments were performed on a Waters Xevo G2 Q-TOF spectrometer or a Bruker APEX IV FTMS instrument.

2. General Procedures

2.1 General procedure for photo-induced glycosylation

4 Å MS (400 mg) was baked at high temperature and cooled under vacuum, then was added to a 10 mL quartz two-necked reaction flask. Under Ar protection, donor (0.030 mmol), Umemoto's reagent (0.038 mmol), $Cu(OTf)_2$ (0.038 mmol), and anhydrous CH_2Cl_2 (4 mL) were added. The reaction mixture was stirred for 15 min and then cooled to -72 °C. The reaction flask was exposed to UV irradiation at -72 °C for 20 min. After disappearance of the donor detected by TLC, the removal of UV irradiation was followed by the addition of a solution of the acceptor (0.025 mmol) in CH_2Cl_2 (0.5 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 1.5 h, and then quenched by Et_3N (0.1 mL). The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate) to give the desired product.



2.2 Procedure for the screening of photo-induced fucosylation

4 Å MS (1.5 g) was baked at high temperature and cooled under vacuum, then was added to a 25 mL reaction flask including quartz top cover. Under Ar protection, donor (0.05 mmol) was added. Umemoto's reagent (0.15 mmol) and $Cu(OTf)_2$ (0.15 mmol) were dissolved or suspended in anhydrous CH_2Cl_2 (7 mL) under ultrasound and then added via syringe. The reaction mixture was stirred for 5 min and then cooled to activation temperature. The reaction flask was exposed to UV irradiation for proper irradiation time. The removal of UV irradiation was followed by the addition of a solution of the acceptor (0.005 mmol) and TTBP (0.075 mmol) in CH_2Cl_2 (2 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 2.5 h, and then quenched by Et_3N (0.1 mL). The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product

was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 2:1, v/v) to give the desired product.

3. The Reaction Condition Screening for Compound 2

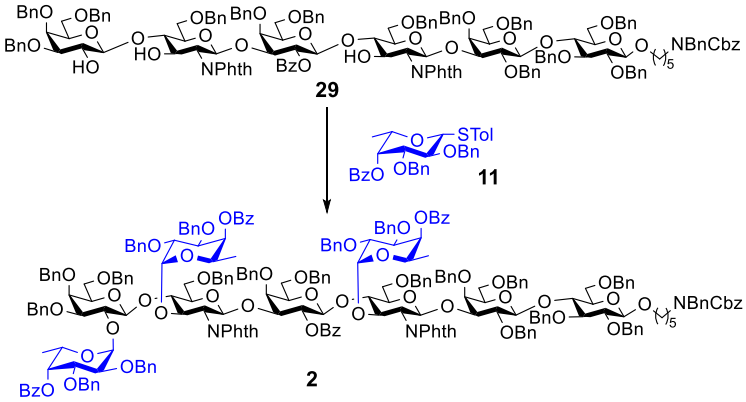
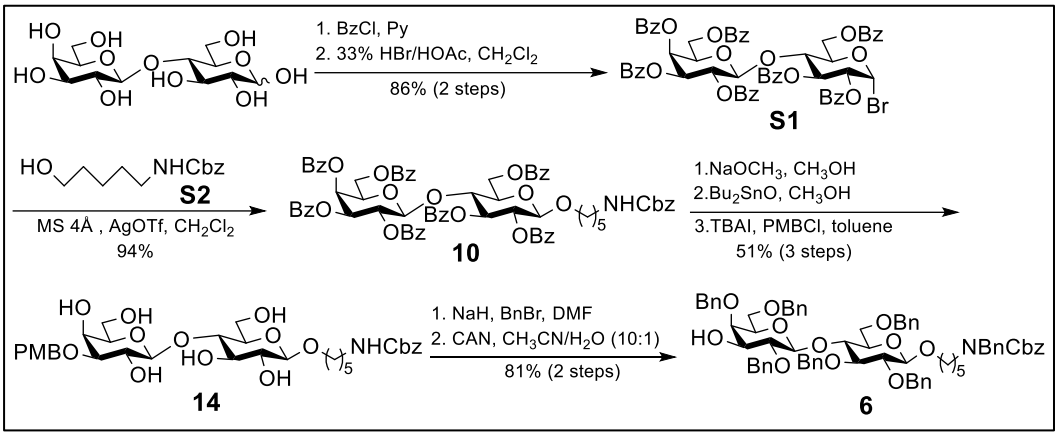


Table S1. Screening of the Photo-Induced Fucosylation

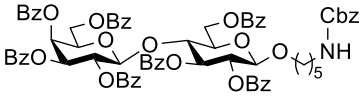
Entry	Activation Temp. (ºC)	UV Irradiation Time (min)	Yield (%)
1	-72	30	—
2	-72	15	—
3	-72	12	—
4	-72	8	—
5	-72	6	Trace
6	-72	4	10%
7	-72	2	—
8	-60	5	68%
9	-50	5	85%
10	-40	5	38%
11	-50	4	90%
12	-50	3	71%

4. Experimental Procedures for the Synthesis of Blocks 6-9, 11

4.1 Synthesis of compound **6**



Compound **10**

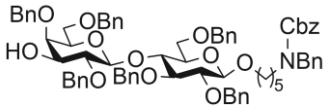


Lactose (6.0 g, 17.5 mmol) was dissolved in pyridine (36 mL), and then BzCl (24 mL, 206.4 mmol) was added under ice bath. Under Ar protection, the reaction was stirred at room temperature overnight. The reaction mixture was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The mixture was filtered and the filtrate was concentrated under reduced pressure. The product obtained was dissolved in CH_2Cl_2 (35 mL) under the protection of Ar, then 33% HBr/HOAc (70 mL) was slowly added under ice bath. The mixture was stirred at room temperature overnight. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The mixture was filtered and the filtrate was concentrated under reduced pressure to afford **S1** as a yellow foamy solid (17.1 g, 86%).

4 Å MS (5g) were added to a two-necked flask. The flask was evacuated and baked, then cooled to room temperature. Under Ar protection, solid **S1** (5.2 g, 4.6 mmol) and compound **S2**[1] (2.2 g, 9.2 mmol) were added. Anhydrous CH_2Cl_2 (30 mL) was added, stirred for 15 min at room temperature. Then, AgOTf (2.4 g) in toluene/CH_2Cl_2 (v/v = 3:1, 20 mL) was added under ice bath. The reaction mixture was stirred for 3 h. The mixture was filtered. The filtrate was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate 1.5:1, v/v) to afford **10** as a white solid (5.6

g, 94%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02-7.89 (m, 12H), 7.72 (d, *J* = 7.4 Hz, 2H), 7.64-7.54 (m, 3H), 7.51-7.46 (m, 5H), 7.42-7.29 (m, 14H), 7.21 (t, *J* = 7.7 Hz, 2H), 7.14 (t, *J* = 7.7 Hz, 2H), 5.79 (t, *J* = 9.6 Hz, 1H), 5.74-5.69 (m, 2H), 5.44 (dd, *J* = 9.0, 7.7 Hz, 1H), 5.37 (dd, *J* = 10.4, 3.4 Hz, 1H), 5.06 (s, 2H), 4.87 (d, *J* = 7.9 Hz, 1H), 4.65 (d, *J* = 7.7 Hz, 1H), 4.62-4.56 (m, 2H), 4.48 (dd, *J* = 12.2, 4.1 Hz, 1H), 4.24 (t, *J* = 9.5 Hz, 1H), 3.88 (t, *J* = 6.5 Hz, 1H), 3.83-3.66 (m, 4H), 3.45-3.39 (m, 1H), 2.90 (dd, *J* = 12.3, 6.2 Hz, 2H), 1.50-1.43 (m, 2H), 1.23-1.11 (m, 2H), 0.90-0.83 (m, 2H). The ^{1}H NMR data are consistent with those reported previously.[2]

Compound **6**

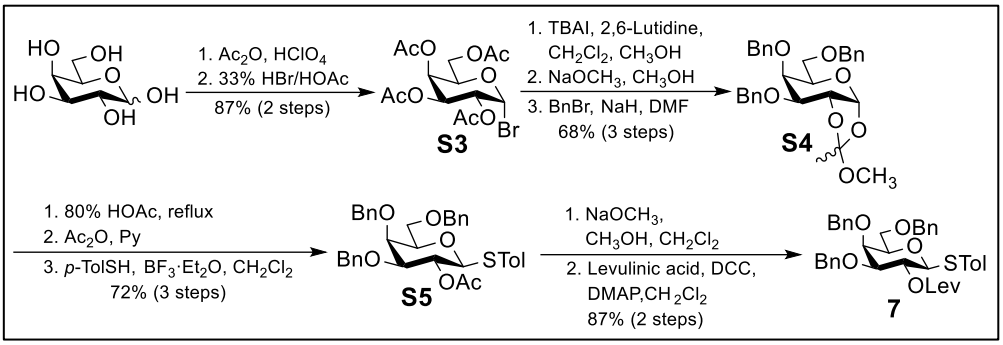


Compound **10** (500 mg, 0.39 mmol) was added to a 100 mL reaction flask, dissolved in methanol (30 mL). NaOMe (200 μL) was added, and the solution was stirred at room temperature for 5 h. The H^+ resin was added to neutralize. The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by recrystallization with petroleum ether and ethyl acetate. The obtained white solid (400 mg, 0.71 mmol) and Bu_2SnO (300 mg, 1.2 mmol) were dissolved in methanol (20 mL) and refluxed at 80 ° C for 20 h under Ar protection. Then it was concentrated under reduced pressure and dried sufficiently under vacuum. Then TBAI (200 mg, 0.62 mmol) was added, and under Ar protection, PMBCl (0.2 mL) was added and dissolved in toluene (20 mL). The mixture was refluxed at 110 ° C for 10 h. It was concentrated under reduced pressure and the crude product was purified by column chromatography on silica gel (petroleum ether: methanol = 20:1, v/v) to afford **14** as a yellow solid (135 mg, 51%) which was directly used for the next step reaction.

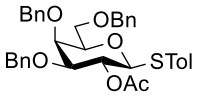
The solid **14** (500 mg, 0.73 mmol) was dissolved in anhydrous DMF (20 mL), and NaH (411 mg, 10.27 mmol) was slowly added in batches in an ice bath, and then BnBr (732 μL, 6.16 mmol) was added. The mixture was stirred at room temperature for 1 h. The reaction was quenched by methanol, and dissolved with CH_2Cl_2, washed sequentially with water, and NaCl aq., and dried over anhydrous Na_2SO_4. The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 10:1, v/v) to afford a white solid (857 mg, 89%). The white solid (132 mg, 0.10 mmol) was dissolved in a solution of CH_3CN: H_2O (v/v = 10:1, 4.4 mL). CAN (110 mg, 0.20 mmol) was added. The reaction mixture was stirred at room temperature for 30 min. The mixture was diluted with CH_2Cl_2,

washed sequentially with water, and NaCl aq., and dried over anhydrous Na_2SO_4. The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 3:1, v/v) to afford **6** as a colorless oil (109 mg, 91%). $[\alpha]_D^{25}$ +0.25 (c 0.73, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36-7.15 (m, 40H), 5.15 (m, 2H), 5.01 (d, *J* = 10.7 Hz, 1H), 4.87-4.55 (m, 8H), 4.47-4.25 (m, 7H), 3.97-3.72 (m, 5H), 3.58-3.36 (m, 9H), 3.23-3.16 (m, 2H), 2.19 (d, *J* = 4.4 Hz, 1H), 1.61-1.26 (m, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.84, 156.25, 139.20, 138.80, 138.79, 138.53, 138.34, 138.11, 138.00, 136.94, 136.93, 136.91, 136.87, 128.58, 128.50, 128.43, 128.42, 128.34, 128.15, 128.05, 127.96, 127.89, 127.80, 127.76, 127.66, 127.62, 127.58, 127.56, 127.32, 127.21, 103.68, 102.74, 82.95, 81.81, 80.71, 76.02, 75.39, 75.21, 75.15, 75.01, 74.97, 74.19, 73.42, 73.28, 73.21, 69.77, 68.41, 68.04, 67.20, 50.62, 50.33, 47.24, 46.27, 29.78, 29.52, 27.98, 27.60, 23.45. HRMS (ESI): $[M + Na]^+$ $C_{74}H_{81}NO_{13}Na^+$ m/z calcd. 1214.5600, found 1214.5610.

4.2 Synthesis of compound **7**



Compound **S5**



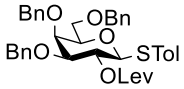
Ac_2O (200 mL) was added to a 500 mL two-necked flask, and after cooling in an ice bath, $HClO_4$ (1 mL) was slowly added dropwise. After the reaction was stable, D-(+)-galactose (40 g, 0.22 mol) was added to the solution in batches, and the temperature was maintained at 10-20 °C. The reaction was performed at room temperature for 30 min. After cooling the reaction solution in ice bath, 33% HBr/HOAc (100 mL) was slowly added. The reaction mixture was stirred at room temperature for 4 h. The reaction solution was poured into ice-water and continuously stirred. Then white solid precipitated. The solid was filtered and dissolved with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 4:1, v/v) to afford **S3** as a white solid (79.62 g, 87%).

The white solid **S3** (4.0 g, 10.0 mmol) and Bu_4NI (1.11 g, 3.0 mmol) was added to a 100 mL three-necked flask. After fully drying under vacuum, anhydrous CH_2Cl_2 (10 mL) was added. Then 2,4-lutidine (1.5 mL, 13.0 mmol) and anhydrous MeOH (0.8 mL, 20 mmol) were added. The reaction mixture was stirred at room temperature for 16 h. The solution was concentrated under reduced pressure. The residue was dissolved in MeOH (10 mL), and NaOMe (2 mL, 10 mmol) was added dropwise. The mixture was stirred at room temperature for 30 min. The solution was concentrated under reduced pressure, and was dried under vacuum for 30 min. The residue was dissolved in DMF (70 mL), NaH (1.8 g, 45 mmol) was added in portions under ice-bath cooling. After no gas released, BnBr (5.4 mL, 45 mmol) was added dropwise. The mixture was stirred at room temperature for 4 h. The

reaction solution was poured into ice water and CH_2Cl_2 (100 mL). The aqueous phase was extracted with CH_2Cl_2 (100 mL x 3). The organic phases were combined, washed with NaCl aq., dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product **S4** was obtained as an oil (3.35 g, 68%).

Compound **S4** (3.5 g) was dissolved in 80% HOAc aqueous solution, and was refluxed at 90 °C for 3 h. The reaction solution was concentrated under reduced pressure. It was dissolved in Py (40 mL), and Ac_2O (20 mL) was slowly added under ice bath cooling, the mixture was then stirred at room temperature overnight. The reaction solution was concentrated under reduced pressure, then was diluted with CH_2Cl_2 (10 mL). The solution was washed with $NaHCO_3$ aq., then the aqueous phase was extracted with CH_2Cl_2 (100 mL x 3). The organic phases were combined, washed with NaCl aq., dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 8:1, v/v) to afford an oily substance (2.99 g, 81.5%). The oily substance (510 mg, 0.9 mmol) and *p*-Toluenethiol (170 mg, 1.4 mmol) were placed into a 100 mL two-necked flask, Under the protection of Ar gas, anhydrous CH_2Cl_2 (50 mL) was added and stirred for 15 min. After slowly adding $BF_3 \cdot Et_2O$ (0.18 mL, 1.4 mmol) in an ice bath cooling, the reaction was stirred at room temperature for 2 h, and monitored by TLC. The solution was washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., then dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 10:1, v/v) to afford **S5** as a white solid (538 mg, 88%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39-7.25 (m, 17H), 7.02 (d, J = 7.9 Hz, 2H), 5.39 (t, J = 9.6 Hz, 1H), 4.93 (d, J = 11.8 Hz, 1H), 4.66 (d, J = 12.2 Hz, 1H), 4.57-4.50 (m, 3H), 4.47-4.39 (m, 2H), 3.97 (d, J = 2.7 Hz, 1H), 3.65-3.58 (m, 3H), 3.55 (dd, J = 9.7, 3.0 Hz, 1H), 2.29 (s, 3H), 2.04 (s, 3H). The ^{1}H NMR data are consistent with those reported previously.[3]

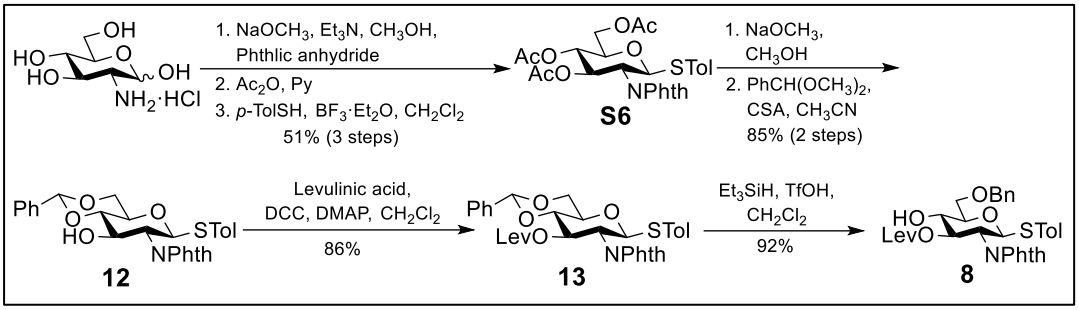
Compound **7**



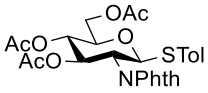
Compound **S5** (420 mg, 0.7 mmol) was dissolved in MeOH (3 mL) and CH_2Cl_2 (3 mL). MeONa (100 μL) was added dropwise with stirring to adjust the pH to 10. The mixture was stirred at room temperature for 5 h. The solution was neutralized with H^+ resin. The mixture was filtered and the filtrate was concentrated under

reduced pressure. After the residue was dissolved in CH_2Cl_2 (5 mL), levulinic acid (137.5 mg, 1.18 mmol), DCC (263 mg, 1.18 mmol) and DMAP (8.6 mg, 0.07 mmol) were added. The mixture was stirred at room temperature for 17 h. It was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 5:1, v/v) to afford **7** as a white solid (370 mg, 87%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39-7.25 (m, 17H), 7.01 (d, *J* = 7.8 Hz, 2H), 5.38 (td, *J* = 9.7, 1.2 Hz, 1H), 4.93 (d, *J* = 11.7 Hz, 1H), 4.66 (d, *J* = 12.4 Hz, 1H), 4.57-4.54 (m, 3H), 4.46-4.38 (m, 2H), 3.95 (s, 1H), 3.65-3.54 (m, 4H), 2.82-2.68 (m, 2H), 2.60-2.56 (m, 2H), 2.29 (s, 3H), 2.16 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 206.31, 171.44, 138.53, 137.96, 137.92, 137.63, 132.57, 129.70, 129.52, 128.43, 128.16, 127.98, 127.90, 127.80, 127.77, 127.62, 127.45, 87.07, 81.51, 77.65, 74.35, 73.59, 72.99, 72.17, 70.20, 68.84, 37.98, 29.90, 28.18, 21.14. The ^{1}H and ^{13}C NMR data are consistent with those reported previously.[4]

4.3 Synthesis of compound **8**



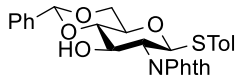
Compound **S6**



D-Glucosamine hydrochloride (4.3 g, 0.02 mol) was suspended in MeOH (100 mL), then MeONa (1.8 mL, 0.02 mol) was slowly dropped under ice bath. After stirring for 1 h, phthalic anhydride (1.62 g, 11 mmol) and Et_3N (2.8 mL, 0.02 mol) were added. The reaction was stirred at room temperature overnight. The solvent was concentrated under reduced pressure to obtain a yellow viscous liquid. After dissolving the residue in Py (50 mL) and cooling the solution in an ice bath, Ac_2O (30 mL) was slowly dripped. The mixture was stirred at room temperature for 6 h. The solution was concentrated under reduced pressure. The concentrate was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. It was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 5:1, v/v) to afford yellow solids (4.62 g, 63%). These solids (4.42 g, 9.3 mmol) and *p*-toluenethiol (1.74 g, 14 mmol) were added to a two-necked flask and dried thoroughly in vacuum. To the flask, $BF_3 \cdot Et_2O$ (5.5 mL, 44 mmol) was added slowly under ice bath and the mixture was stirred overnight at room temperature. The reaction was quenched by adding $NaHCO_3$ aq. (50 mL). The aqueous phase was extracted with CH_2Cl_2 (50 mL x 3), and the organic phases were combined. The solution was washed sequentially with NaCl aq., then dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 5:1, v/v) to afford **S6** as a light yellow solid (3.87 g, 81%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89-7.86 (m, 2H), 7.77-7.75 (m, 2H), 7.30 (d, J = 8.0 Hz, 2H), 7.07 (d, J = 8.0 Hz, 2H), 5.77 (t, J = 19.7 Hz, 1H), 5.65 (d, J = 10.7 Hz, 1H), 5.12 (t, J = 9.9 Hz, 1H), 4.35-4.19 (m, 3H), 3.90-3.86 (m, 1H), 2.33 (s, 3H), 2.11 (s, 3H), 2.02 (s, 3H), 1.84

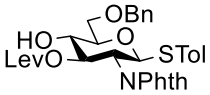
(s, 3H). The ^{1}H NMR data are consistent with those reported previously.[5]

Compound **12**



Compound **S6** (5.7 g, 10.5 mmol) was dissolved in MeOH (120 mL) and CH_2Cl_2 (40 mL), and MeONa (0.2 mL, 1.1 mmol) was added dropwise with stirring. The mixture was stirred at room temperature for 30 min. The solution was neutralized with H^+ resin. The mixture was filtered and the filtrate was concentrated under reduced pressure, then dried under vacuum for 30 min. The residue was dissolved in anhydrous MeCN (100 mL), CSA (0.15 g, 0.65 mmol) and benzaldehyde dimethyl acetyl (3.44 mL, 22.6 mmol) were added, then the reaction was performed at room temperature for 12 h. Appropriate amount of $NaHCO_3$ aq. was added to neutralize CSA. The aqueous phase was extracted with ethyl acetate (100 mL x 3), and the organic phases were combined. The solution was washed sequentially with NaCl aq., then dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 3:1, v/v) to afford **12** as a light yellow solid (4.50 g, 85%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80-7.75 (m, 2H), 7.63-7.60 (m, 2H), 7.44-7.42 (m, 2H), 7.29-7.25 (m, 4H), 7.03 (d, J = 7.5 Hz, 2H), 5.56 (d, J = 10.7 Hz, 1H), 5.49 (s, 1H), 4.54-4.49 (m, 1H), 4.32-4.21 (m, 2H), 4.06-4.01 (m, 1H), 3.73 (t, J = 9.8 Hz, 1H), 3.56-3.45 (m, 2H), 3.33 (s, 1H), 2.26 (s, 3H). The ^{1}H NMR data are consistent with those reported previously.[5]

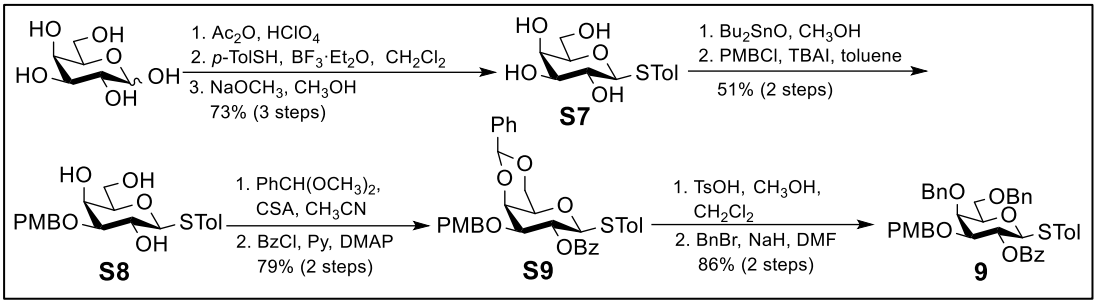
Compound **8**



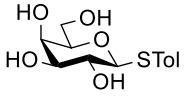
Compound **12** (5.7 g, 11.0 mmol) and levulinic acid (1.63 g, 14.0 mmol) were dissolved in anhydrous CH_2Cl_2 (50 mL). DCC (3.4 g, 16.5 mmol) and DMAP (0.13 g, 1.1 mmol) were added at room temperature and stirred for 12 h. DCU was removed by filtration, and the filtrate was concentrated. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 5:1, v/v) to afford **13** as a white solid (6.1 g, 86%). Compound **13** (120 mg, 0.2 mmol) was dissolved in CH_2Cl_2 (2 mL), and triethylsilane (38 μL, 0.24 mmol) was added. Trifluoromethanesulfonic acid (35 μL, 0.4 mmol) was slowly added dropwise at -78 ° C. After the mixture was stirred for 15 min (by TLC monitoring),

the reaction was quenched by the addition of triethylamine. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 5:1, v/v) to afford **8** as a white solid (111 mg, 92%). $[\alpha]_D^{25}$ +2.34 (c 0.30, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87-7.83 (m, 2H), 7.75-7.69 (m, 2H), 7.38-7.29 (m, 7H), 7.00 (d, *J* = 8.1 Hz, 2H), 5.73-5.65 (m, 2H), 4.62 (d, *J* = 12.1 Hz,1H), 4.58 (d, *J* = 12.1 Hz, 1H), 4.30 (t, *J* = 10.3 Hz, 1H), 3.89-3.74 (m, 4H), 2.59 (t, *J* = 6.3 Hz, 2H), 2.45-2.31 (m, 2H), 2.28 (s, 3H), 1.98 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 206.85, 172.81, 167.85, 167.36, 138.28, 138.05, 134.16, 134.01, 133.40, 131.75, 131.55, 129.63, 129.04, 128.41, 128.23, 127.87, 127.70, 123.57, 83.41, 78.72, 74.82, 73.67, 70.77, 69.98, 53.50, 38.12, 29.47, 28.03, 21.13. HRMS (ESI): $[M + NH_4]^+$ $C_{33}H_{37}N_2O_8S^+$ m/z calcd. 621.2265, found 621.2256.

4.4 Synthesis of compound **9**

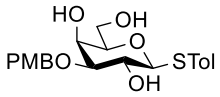


Compound **S7**



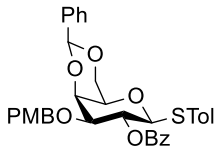
Ac_2O (100 mL) was added to a 250 mL round-bottomed flask, and after cooling in an ice bath, $HClO_4$ (1 mL) was slowly added dropwise. After the reaction was stable, D-galactose (24.0 g, 130 mmol) was added to the solution in batches, and the temperature was maintained at 10-20 °C. The reaction was performed at room temperature for 30 min. The reaction was quenched by adding $NaHCO_3$ aq., then washed sequentially with water, and NaCl aq., and dried over anhydrous Na_2SO_4. The mixture was filtered and the filtrate was concentrated under reduced pressure. After fully drying, *p*-toluenethiol (24.5 g, 200 mmol) was added, directly dissolved in anhydrous CH_2Cl_2 (200 mL), then $BF_3{\cdot}Et_2O$ (20 mL, 130 mmol) was slowly added dropwise under ice bath. The reaction was performed at room temperature for 6 h. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. It was filtered and the filtrate was concentrated under reduced pressure. The crude product was recrystallized with petroleum ether and ethyl acetate (v/v = 3: 1) to obtain a white flocculent solid (48.0 g, 79%). That solid (29.0 g, 64 mmol) was dissolved in methanol (250 mL), then MeONa (0.2 mL) was added, and stirred at room temperature for 5 h. The solution was neutralized with H^+ resin. The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was recrystallized with petroleum ether and ethyl acetate (v/v = 2:1) to obtain **S7** as a white solid (17.11 g, 93%). ^{1}H NMR (400 MHz, CD_3OD) δ 7.45 (d, J = 7.4 Hz, 2H), 7.12 (d, J = 7.7 Hz, 2H), 4.50 (d, J = 9.5 Hz, 1H), 3.88 (s, 1H), 3.77-3.68 (m, 2H), 3.60-3.47 (m, 3H), 2.31 (s, 3H). The ^{1}H NMR data are consistent with those reported previously.[6]

Compound **S8**



Compound **S7** (7.3 g, 25.5 mmol) and Bu_2SnO (9.52 g, 38.3 mmol) were dissolved in methanol (150 mL) and refluxed at 80 ° C for 16 h under Ar protection. Then it was concentrated under reduced pressure and dried sufficiently under vacuum. Then TBAI (4.58 g, 12.4 mmol) was added, and under Ar protection, PMBCl (5.2 mL, 38.3 mmol) was added and dissolved in toluene (130 mL). The solution was refluxed at 110 ° C for 6 h. It was concentrated under reduced pressure and the crude product was purified by column chromatography on silica gel (petroleum ether: methanol = 3:1, v/v) to afford **S8** as a light yellow solid (5.3 g, 51 %). ^{1}H NMR (400 MHz, CD_3OD) δ 7.45 (d, *J* = 8.2 Hz, 2H), 7.35 (d, *J* = 8.6 Hz, 2H), 7.11 (d, *J* = 7.9 Hz, 2H), 6.88 (d, *J* = 8.6 Hz, 2H), 4.69 (d, *J* = 11.3 Hz, 1H), 4.61 (d, *J* = 11.3 Hz, 1H), 4.51 (d, *J* = 9.9 Hz, 1H), 4.04 (d, *J* = 3.0 Hz, 1H), 3.77 (s, 3H), 3.75– 3.67 (m, 3H), 3.47 (t, *J* = 6.1 Hz, 1H), 3.37 (dd, *J* = 9.2, 3.2 Hz, 1H), 2.30 (s, 3H). The ^{1}H NMR data are consistent with those reported previously.[7]

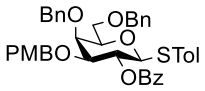
Compound **S9**



Compound **S8** (500 mg, 1.23 mmol) was dissolved in anhydrous MeCN (25 mL), CSA (catalytic amount) and benzaldehyde dimethyl acetyl (225 μL, 1.5 mmol) were added, then the reaction was performed at room temperature for 3 h. Et_3N was added to quench the reaction. The solution was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: methanol = 1:1, v/v) to afford a light yellow solid (526 mg, 86 %). The solid (360 mg, 0.73 mmol) and DMAP (4.5 mg, 0.043 mmol) was dissolved in pyridine (12 mL), and then BzCl (90 μL, 0.78 mmol) was added under ice bath. Under Ar protection, the reaction was stirred at room temperature for 6 h. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 1:1, v/v) to afford **S9** as a white solid (402 mg, 92%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, *J* = 7.6 Hz, 2H), 7.59 (t, *J* = 7.4 Hz, 1H), 7.48-7.35 (m, 9H), 7.08-7.02 (m, 4H), 6.64 (d, *J* = 7.8

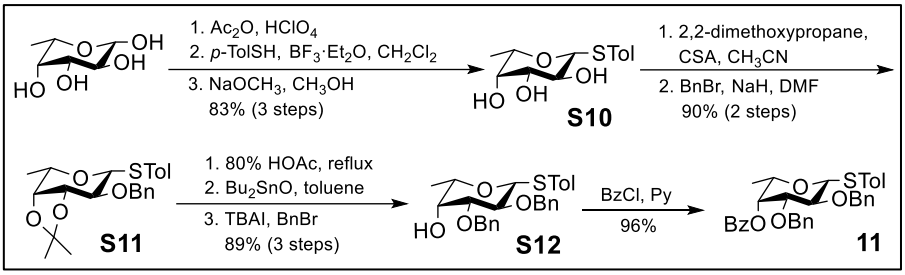
Hz, 2H), 5.49-5.45 (m, 2H), 4.73 (d, *J* = 9.8 Hz, 1H), 4.54 (d, *J* = 12.4 Hz, 1H), 4.46 (d, *J* = 12.4 Hz, 1H), 4.35 (d, *J* = 12.3 Hz, 1H), 4.19 (s, 1H), 4.00 (d, *J* = 12.2 Hz, 1H), 3.73 (s, 1H), 3.71 (s, 3H), 3.45 (s, 1H), 2.31 (s, 3H). The ^{1}H NMR data are consistent with those reported previously.[6]

Compound **9**



Compound **S9** (240 mg, 0.40 mmol) was dissolved in CH_2Cl_2 (4 mL) and MeOH (2 mL), then TsOH (11.5 mg, 0.067 mmol) was added. The mixture was stirred at room temperature for 6 h. Et_3N was added to quench the reaction. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 3:1, v/v) to afford a white solid (184 mg, 90 %). That solid (92 mg, 0.18 mmol) was dissolved in anhydrous DMF (4 mL), and NaH (70 mg, 0.87 mmol) was slowly added in batches under ice bath, and then BnBr (53 μL, 0.44 mmol) was added. The mixture was stirred at room temperature for 1 h. Methanol was added to quench the reaction. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 4:1, v/v) to afford **9** as a white solid (118 mg, 95 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02-7.99 (m, 2H), 7.59-7.56 (m, 1H), 7.45 (t, *J* = 7.8 Hz, 2H), 7.35-7.26 (m, 12H), 7.05 (d, *J* = 8.8 Hz, 2H), 6.98 (d, *J* = 8.0 Hz, 2H), 6.65-6.63 (m, 2H), 5.62 (t, *J* = 9.6 Hz, 1H), 4.98 (d, *J* = 11.7 Hz, 1H), 4.69 (d, *J* = 10.0 Hz, 1H), 4.57 (t, *J* = 11.7 Hz, 2H), 4.48-4.39 (m, 3H), 3.99 (d, *J* = 2.5 Hz, 1H), 3.71 (s, 3H), 3.69-3.64 (m, 4H), 2.27 (s, 3H). The ^{1}H NMR data are consistent with those reported previously.[7]

4.5 Synthesis of compound **11**



Compound **11**

Ac_2O (40 mL) was added to a 100 mL round-bottomed flask, and after cooling in an ice bath, $HClO_4$ (0.4 mL) was slowly added dropwise. After the reaction was stable, L-fucose (8.0 g, 48.8 mmol) was added to the solution in batches, and the temperature was maintained at 10-20 °C. The reaction was performed at room temperature for 30 min. The reaction was quenched by adding $NaHCO_3$ aq., then washed sequentially with water, and NaCl aq., and dried over anhydrous Na_2SO_4. It was filtered and the filtrate was concentrated under reduced pressure. After fully drying, *p*-toluenethiol (9.1 g, 73.2 mmol) was added, directly dissolved in anhydrous CH_2Cl_2 (200 mL), then $BF_3·Et_2O$ (11.3 mL, 73.2 mmol) was slowly added dropwise under ice bath. The reaction was performed at room temperature for 6 h. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was recrystallized with petroleum ether and ethyl acetate (v/v = 3:1) to obtain a white solid. That solid (11.0 g, 28 mmol) was dissolved in methanol (200 mL), then MeONa (0.2 mL) was added, and the mixture was stirred at room temperature for 2 h. The solution was neutralized with H^+ resin. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was recrystallized with petroleum ether and ethyl acetate (v/v = 2:1) to obtain **S10** as a white solid (15.03 g, 83%).

Compound **S10** (700 mg, 2.6 mmol) was dissolved in anhydrous CH_3CN (15 mL), then 2,2-dimethoxypropane (690 uL, 5.6 mmol) and CSA (catalytic amount) were added. The mixture was stirred at room temperature for 3 h. Et_3N was added to quench the reaction. The solution was concentrated under reduced pressure. The residue was dissolved in anhydrous DMF (15 mL), and NaH (224 mg, 5.6 mmol) was slowly added in batches under ice bath, and then BnBr (400 uL, 3.36 mmol) was added. The mixture was stirred at room temperature for 1 h. Methanol was

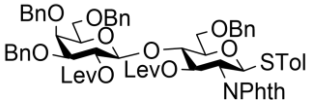
added to quench the reaction. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 10:1, v/v) to afford **S11** as a white solid (936 mg, 90%).

Compound **S11** (800 mg, 2 mmol) was dissolved in 80% HOAc aqueous solution, and was refluxed at 90 °C for 30 min. The solution was concentrated under reduced pressure to obtain a white solid (675 mg, 94%). That solid (280 mg, 0.78 mmol) and Bu_2SnO (290 mg, 1.17 mmol) were dissolved in methanol (10 mL) and refluxed at 80 °C for 8 h under Ar protection. Then TBAI (144 mg, 0.39 mmol) was added, BnBr (140 μL, 1.17 mmol) was added and the solution was refluxed at 110 ° C for 10 h. It was concentrated under reduced pressure and the crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 5:1, v/v) to afford **S12** as a white solid (333 mg, 95%).

Compound **S12** (108 mg, 0.24 mmol) was dissolved in pyridine (3 mL), and then BzCl (83 μL, 0.72 mmol) was added under ice bath. Under Ar protection, the reaction was stirred at room temperature overnight. The solution was diluted with CH_2Cl_2, washed sequentially with $NaHCO_3$ aq., water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 15:1, v/v) to afford **11** as a white solid (128 mg, 96 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05-8.02 (m, 2H), 7.62-7.56 (m, 3H), 7.47-7.39 (m, 4H), 7.36-7.21 (m, 8H), 7.15 (d, J = 7.9 Hz, 2H), 5.62 (d, J = 3.2 Hz, 1H), 4.79 (d, J = 11.4 Hz, 1H), 4.73 (d, J = 2.3 Hz, 2H), 4.61 (d, J = 9.5 Hz, 1H), 4.52 (d, J = 11.3 Hz, 1H), 3.83-3.78 (m, 1H), 3.75 (dd, J = 9.1, 3.2 Hz, 1H), 3.67 (t, J = 9.3 Hz, 1H), 2.38 (s, 3H), 1.30 (d, J = 6.4 Hz, 3H). The ^{1}H NMR data are consistent with those reported previously.[8]

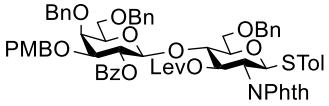
5. Experimental Procedures for the Assembly of Nonasaccharide and Deprotection

5.1 Synthesis of compound **4**



4 Å MS (400 mg) was added to a 10 mL quartz two-necked reaction flask, and baked at high temperature and cooled under vacuum. Under Ar protection, compound **7** (20.0 mg, 30.5 μmol), Umemoto's reagent (14.0 mg, 38.2 μmol), $Cu(OTf)_2$ (15.3 mg, 38.2 μmol), and anhydrous CH_2Cl_2 (4 mL) were added. The reaction mixture was stirred for 15 min and then cooled to -72 °C. The reaction flask was exposed to UV irradiation at -72 °C for 20 min. After disappearance of **7** detected by TLC, the removal of UV irradiation was followed by the addition of a solution of compound **8** (15.4 mg, 25.5 μmol) in CH_2Cl_2 (0.5 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 1.5 h, and then quenched by Et_3N (0.1 mL). The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 2:1, v/v) to afford **4** as white solids (24.0 mg, 83% yield). $[\alpha]_D^{25}$ +1.9 (c 0.23, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86-7.81 (m, 2H), 7.71-7.69 (m, 2H), 7.35-7.18 (m, 22H), 7.00 (d, *J* = 7.6 Hz, 2H), 5.69 (t, *J* = 9.8 Hz, 1H), 5.61 (d, *J* = 10.5 Hz, 1H), 5.14 (t, *J* = 8.9 Hz, 1H), 4.86 (d, *J* = 11.4 Hz, 1H), 4.69 (d, *J* = 11.9 Hz, 1H), 4.62 (d, *J* = 12.2 Hz, 1H), 4.49-4.37 (m, 6H), 4.24 (t, *J* = 10.4 Hz, 1H), 3.95-3.78 (m, 4H), 3.68 (d, *J* = 9.7 Hz, 1H), 3.57-3.48 (m, 2H), 3.38-3.33 (m, 2H), 2.68-2.66 (m, 2H), 2.46-2.28 (m, 4H), 2.27 (s, 3H), 2.24-2.16 (m, 2H), 2.14 (s, 3H), 1.72 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 206.33, 206.25, 171.86, 171.09, 167.81, 167.31, 138.61, 138.29, 138.01, 137.82, 134.00, 133.87, 133.67, 131.75, 131.66, 129.61, 129.05, 128.52, 128.40, 128.24, 128.17, 127.94, 127.91, 127.89, 127.82, 127.70, 127.67, 127.65, 127.42, 123.57, 123.53, 100.41, 83.20, 80.43, 79.20, 74.55, 74.48, 73.55, 73.46, 73.10, 72.59, 72.04, 71.99, 71.90, 68.03, 67.86, 53.92, 37.84, 37.69, 29.88, 29.33, 27.90, 27.88, 21.15. HRMS (ESI): $[M + NH_4]^+$ $C_{65}H_{71}N_2O_{15}S^+$ m/z calcd. 1151.4570, found 1151.4548.

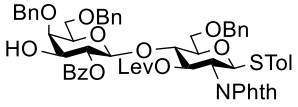
5.2 Synthesis of compound **15**



4 Å MS (400 mg) was added to a 10 mL quartz two-necked reaction flask, and

baked at high temperature and cooled under vacuum. Under Ar protection, compound **9** (20.0 mg, 29.0 μmol), Umemoto's reagent (16.5 mg, 48.3 μmol), $Cu(OTf)_2$ (14.5 mg, 36.2 μmol), and anhydrous CH_2Cl_2 (4 mL) were added. The reaction mixture was stirred for 15 min and then cooled to -72 °C. The reaction flask was exposed to UV irradiation at -72 °C for 20 min. After disappearance of **9** detected by TLC, the removal of UV irradiation was followed by the addition of a solution of compound **8** (14.6 mg, 24.1 μmol) and TTBP (10.8 mg, 34.5 μmol) in CH_2Cl_2 (0.5 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 1.5 h, and then quenched by Et_3N (0.1 mL). The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 2:1, v/v) to afford **15** as a white solid (24.0 mg, 82% yield). $[\alpha]_D^{25}$ +3.73 (c 0.21, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (d, *J* = 8.3 Hz, 2H), 7.86-7.80 (m, 2H), 7.70-7.68 (m, 2H), 7.56 (t, *J* = 7.5 Hz, 1H), 7.43-7.16 (m, 19H), 7.03 (d, *J* = 8.2 Hz, 2H), 6.94 (d, *J* = 7.8 Hz, 2H), 6.64 (d, *J* = 8.3 Hz, 2H), 5.68 (t, *J* = 10.2 Hz, 1H), 5.52 (dd, *J* = 10.5, 1.5 Hz, 1H), 5.42 (t, *J* = 9.0 Hz, 1H), 4.94 (d, *J* = 11.4 Hz, 1H), 4.56-4.42 (m, 6H), 4.36-4.20 (m, 3H), 3.95-3.91 (m, 2H), 3.73 (s, 3H), 3.63-3.48 (m, 7H), 2.42-2.27 (m, 3H), 2.23 (s, 3H), 2.22-2.16 (m, 1H), 1.74 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 206.27, 171.82, 167.71, 167.34, 164.76, 159.17, 138.66, 138.35, 138.19, 137.83, 134.00, 133.84, 133.49, 132.99, 131.76, 131.68, 130.02, 129.85, 129.75, 129.55, 129.22, 129.05, 128.54, 128.35, 128.22, 128.00, 127.91, 127.80, 127.67, 127.63, 127.48, 125.32, 123.55, 113.70, 100.65, 83.28, 79.49, 78.74, 74.77, 74.55, 73.53, 73.31, 73.25, 72.39, 72.25, 72.11, 71.14, 67.95, 67.90, 55.18, 53.90, 37.71, 29.37, 27.89, 21.49, 21.12. HRMS (ESI): $[M + NH_4]^+$ $C_{68}H_{71}N_2O_{15}S^+$ m/z calcd. 1187.4570, found 1187.4560.

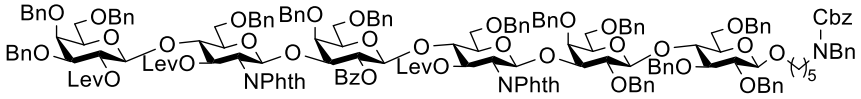
5.3 Synthesis of compound **5**



Compound **15** (40.0 mg, 34.2 μmol) was dissolved in a solution of CH_3CN/H_2O (v/v = 10: 1, 4.4 mL). CAN (137 mg, 68.4 umol) was added. The mixture was stirred at room temperature for 30 min. The mixture was diluted with CH_2Cl_2, washed sequentially with water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 3:1, v/v) to afford **5** as a white solid (32.4 mg, 90% yield). $[\alpha]_D^{25}$ +0.86 (c 0.46, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96-7.94 (m, 2H), 7.87-7.80 (m, 2H), 7.72-7.69 (m, 2H), 7.54 (t, *J* = 7.5 Hz, 1H), 7.42-7.25 (m,

19H), 6.97 (d, *J* = 8.2 Hz, 2H), 5.70 (dd, *J* = 9.9, 9.3 Hz, 1H), 5.54 (d, *J* = 10.4 Hz, 1H), 5.07 (dd, *J* = 8.9, 7.8 Hz, 1H), 4.70-4.48 (m, 6H), 4.41 (d, *J* = 12.2 Hz, 1H), 4.26 (t, *J* = 10.4 Hz, 1H), 3.98 (t, *J* = 9.3 Hz, 1H), 3.89 (d, *J* = 3.4 Hz, 1H), 3.75 (dd, *J* = 11.5, 3.6 Hz, 1H), 3.65-3.54 (m, 6H), 2.49-2.24 (m, 4H), 2.23 (s, 3H), 1.80 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 206.02, 171.82, 167.74, 167.33, 166.33, 138.27, 138.24, 138.15, 137.66, 134.02, 133.89, 133.56, 133.24, 131.72, 131.67, 129.79, 129.66, 129.59, 128.57, 128.55, 128.45, 128.42, 127.96, 127.93, 127.86, 127.79, 127.75, 127.73, 123.57, 100.10, 83.32, 78.84, 76.41, 75.40, 74.79, 74.40, 73.50, 73.45, 73.30, 73.08, 71.98, 67.90, 67.68, 53.88, 37.73, 29.39, 27.90, 21.13. HRMS (ESI): $[M + NH_4]^+ C_{60}H_{63}N_2O_{14}S^+$ m/z calcd. 1067.3995, found 1067.3984.

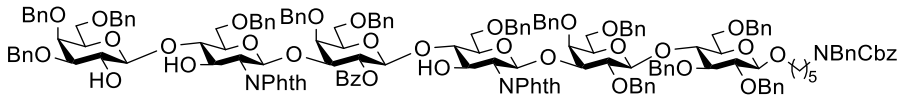
5.4 Synthesis of compound **3**



4 Å MS (400 mg) was added to a 10 mL quartz two-necked reaction flask, and baked at high temperature and cooled under vacuum. Under Ar protection, compound **4** (20.0 mg, 17.6 μmol), Umemoto's reagent (16.0 mg, 44.1 μmol), $Cu(OTf)_2$ (18.0 mg, 44.1 μmol), and anhydrous CH_2Cl_2 (4 mL) were added. The reaction mixture was stirred for 15 min and then cooled to -72 °C. The reaction flask was exposed to UV irradiation at -72 °C for 20 min. After disappearance of **4** detected by TLC, the removal of UV irradiation was followed by the addition of a solution of compound **5** (15.4 mg, 14.7 μmol) and TTBP (6.6 mg, 26.4 μmol) in CH_2Cl_2 (0.5 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 1.5 h. The reaction was cooled to -72 °C. Umemoto's reagent (16.0 mg, 44.1 μmol) and $Cu(OTf)_2$ (18.0 mg, 44.1 μmol) were added. The reaction flask was exposed to UV irradiation at -72 °C for 20 min. After disappearance of the starting material detected by TLC, the removal of UV irradiation was followed by the addition of a solution of compound **6** (16.0 mg, 13.2 μmol) and TTBP (6.6 mg, 26.4 μmol) in CH_2Cl_2 (0.5 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 1.5 h, and then quenched by Et_3N (0.1 mL). The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 1:1, v/v) to afford **3** as a white solid (50.0 mg, 61% yield). $[\alpha]_D^{25}$ -10.3 (c 0.24, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.71 (d, *J* = 7.2 Hz, 1H), 7.62 (d, *J* = 6.9 Hz, 1H), 7.56-7.49 (m, 4H), 7.46 (t, *J* = 7.2 Hz, 1H), 7.35-7.08 (m, 71H), 7.03 (t, *J* = 7.5 Hz, 2H), 6.82 (s, 3H), 5.66 (dd, *J* = 9.8, 9.1 Hz, 1H), 5.59 (dd, *J* = 10.0, 9.3 Hz, 1H), 5.40 (d, *J* = 8.2 Hz, 1H), 5.36 (d, *J* = 8.4 Hz, 1H), 5.16-5.12 (m, 4H), 5.03 (d, *J* = 11.6 Hz, 1H), 4.97 (d, *J* = 11.4 Hz, 1H), 4.84 (d, *J* =

11.4 Hz, 2H), 4.78-4.74 (m, 1H), 4.65-4.60 (m, 3H), 4.53-4.35 (m, 16H), 4.28 (d, *J* = 11.8 Hz, 1H), 4.21-4.11 (m, 9H), 3.98 (d, *J* = 11.8 Hz, 1H), 3.93-3.86 (m, 5H), 3.82-3.70 (m, 5H), 3.54-3.46 (m, 5H), 3.43-3.19 (m, 16H), 3.11 (m, 1H), 2.88 (d, *J* = 9.6 Hz, 1H), 2.78-2.74 (m, 1H), 2.65-2.60 (m, 1H), 2.48-2.44 (m, 1H), 2.42-2.10 (m, 12H), 1.67-1.66 (m, 9H), 1.55-1.43 (m, 4H), 1.26-1.21 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 206.57, 206.38, 206.18, 171.62, 171.53, 171.04, 167.41, 167.38, 167.33, 167.05, 164.05, 156.65, 156.09, 139.35, 138.99, 138.97, 138.67, 138.49, 138.37, 138.29, 138.26, 137.95, 137.91, 137.85, 137.66, 136.81, 136.73, 133.54, 133.34, 133.23, 132.63, 131.22, 131.16, 131.08, 130.90, 129.69, 129.35, 128.51, 128.46, 128.43, 128.39, 128.35, 128.20, 128.18, 128.16, 128.12, 128.11, 128.06, 128.02, 127.99, 127.92, 127.86, 127.83, 127.80, 127.77, 127.72, 127.65, 127.60, 127.41, 127.38, 127.32, 127.30, 127.09, 126.94, 126.64, 126.35, 123.30, 123.20, 123.02, 122.85, 103.41, 102.27, 100.41, 100.31, 99.46, 99.27, 82.84, 82.19, 81.53, 80.69, 80.32, 78.52, 76.53, 76.27, 75.88, 75.29, 75.07, 74.96, 74.88, 74.83, 74.59, 74.48, 74.42, 74.37, 73.95, 73.92, 73.62, 73.42, 73.38, 73.36, 73.17, 73.13, 72.97, 72.82, 72.80, 72.32, 71.98, 71.76, 71.48, 70.33, 70.24, 69.57, 69.47, 68.25, 68.18, 67.98, 67.62, 67.45, 67.08, 55.05, 54.81, 50.47, 50.15, 47.10, 46.14, 37.75, 37.63, 37.62, 29.89, 29.30, 29.24, 27.82, 27.77, 23.29, 27.46, 23.25. HRMS (ESI): $[M + 2NH_4]^{2+}$ $C_{185}H_{199}N_5O_{42}^{2+}$ m/z calcd. 1581.1789, found 1581.1859.

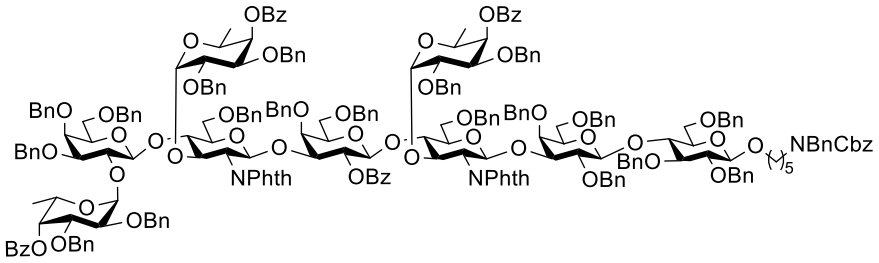
5.5 Synthesis of compound **16**



Compound **3** (50.0 mg, 16 μmol) was dissolved in a solution of THF/MeOH (v/v = 10: 1, 4.4 mL). H_2NNH_2·HOAc (22.0 mg, 240 μmol) was added. The mixture was stirred at room temperature overnight. The mixture was diluted with CH_2Cl_2, washed sequentially with water, and NaCl aq., and dried over anhydrous Na_2SO_4. The solution was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether: ethyl acetate: CH_2Cl_2 = 1:1:0.25, v/v/v) to afford **16** as a white solid (41.5 mg, 90% yield). $[\alpha]_D^{25}$ -0.78 (c 0.44, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.6 Hz, 1H), 7.66-7.65 (m, 3H), 7.57-7.54 (m, 2H), 7.46 (t, *J* = 7.5 Hz, 1H), 7.38-7.08 (m, 74H), 7.03-7.00 (m, 4H), 6.91 (d, *J* = 7.6 Hz, 1H), 6.85-6.83 (m, 2H), 5.43 (dd, *J* = 9.0, 8.3 Hz, 1H), 5.31 (d, *J* = 8.4 Hz, 1H), 5.28 (d, *J* = 8.5 Hz, 1H), 5.13 (d, *J* = 9.5 Hz, 2H), 5.01 (d, *J* = 11.6 Hz, 2H), 4.97 (d, *J* = 11.4 Hz, 1H), 4.84 (d, *J* = 10.4 Hz, 1H), 4.81 (d, *J* = 11.4 Hz, 1H), 4.76 (t, *J* = 11.7 Hz, 1H), 4.68 (d, *J* = 12.1 Hz, 1H), 4.64-4.50 (m, 7H), 4.47-4.36 (m, 8H), 4.29-4.08 (m, 14H), 4.03-4.01 (m, 2H), 3.93-3.86 (m, 5H), 3.82-3.73 (m, 6H), 3.65-3.63 (m, 1H), 3.60-3.36

(m, 11H), 3.32-3.17 (m, 10H), 3.12-3.10 (m, 1H), 2.91-2.89 (m, 1H), 2.62-2.61 (m, 1H), 1.55-1.42 (m, 4H), 1.30-1.21 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 167.69, 167.65, 167.60, 167.28, 164.24, 156.64, 156.07, 139.38, 139.00, 138.67, 138.45, 138.39, 138.33, 138.28, 138.17, 138.06, 137.84, 137.79, 137.31, 137.23, 136.79, 136.70, 133.44, 133.33, 132.83, 131.42, 131.35, 131.12, 129.74, 129.34, 128.69, 128.53, 128.44, 128.36, 128.26, 128.20, 128.18, 128.15, 128.14, 128.11, 128.09, 128.04, 128.01, 127.92, 127.84, 127.80, 127.74, 127.72, 127.64, 127.62, 127.59, 127.52, 127.49, 127.45, 127.38, 127.29, 127.26, 127.07, 126.97, 126.90, 126.64, 126.38, 123.30, 122.98, 122.95, 122.59, 104.16, 103.39, 102.25, 101.64, 99.74, 99.42, 83.31, 82.83, 81.99, 81.95, 81.89, 81.50, 80.31, 78.60, 76.63, 75.90, 75.44, 75.27, 74.87, 74.80, 74.59, 74.55, 74.43, 73.97, 73.81, 73.46, 73.44, 73.41, 73.32, 73.09, 72.96, 72.83, 72.63, 72.44, 72.34, 71.13, 70.95, 69.53, 69.46, 69.18, 68.99, 68.89, 68.40, 68.36, 68.28, 67.58, 67.06, 56.40, 56.01, 50.46, 50.14, 47.09, 46.13, 29.31, 29.27, 29.22, 27.85, 27.44, 23.29, 23.24. HRMS (ESI): $[M + 2NH_4]^{2+}$ $C_{170}H_{181}N_5O_{36}^{2+}$ m/z calcd. 1434.1238, found 1434.1300.

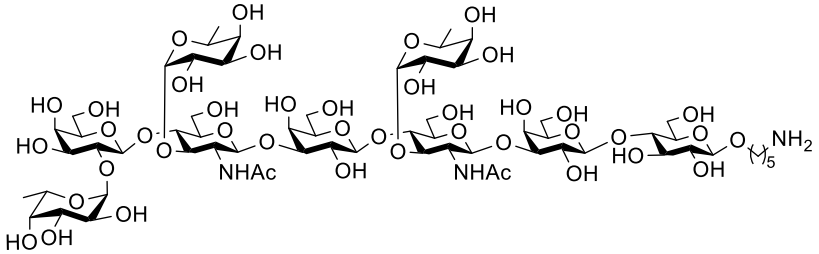
5.6 Synthesis of compound **2**



4 Å MS (1.5 g) was baked at high temperature and cooled under vacuum, then was added to a 25 mL quartz three-necked reaction flask. Under Ar protection, donor **11** (30.0 mg, 54.1 μmol) was added. Umemoto's reagent (64.0 mg, 0.16 mmol) and $Cu(OTf)_2$ (59.0 mg, 0.16 mmol) were dissolved or suspended in anhydrous CH_2Cl_2 (7.0 mL) under ultrasound and then added via syringe. The reaction mixture was stirred for 5 min and then cooled to -50 ºC. The reaction flask was exposed to UV irradiation for 4 min. The removal of UV irradiation was followed by the addition of a solution of the acceptor **16** (13.0 mg, 5.4 μmol) and TTBP (20.0 mg, 81.1 μmol) in CH_2Cl_2 (2.0 mL) via syringe. The reaction mixture was stirred and slowly warmed to room temperature in 2.5 h, and then quenched by Et_3N (0.1 mL). The mixture was filtered and the filtrate was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (petroleum ether: ethyl acetate = 2:1, v/v) to afford **2** as a white solid (36.0 mg, 90% yield). $[\alpha]_D^{25}$ -5.21 (c 0.37, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.05 (d, *J* = 7.2 Hz, 2H), 7.83 (d, *J* = 7.5 Hz, 2H), 7.72 (t, *J* = 7.8 Hz, 5H), 7.62-7.57 (m, 4H), 7.54-7.43 (m, 9H),

7.36-7.03 (m, 96H), 7.00-6.94 (m, 5H), 6.83-6.82 (m, 2H), 6.76-6.70 (m, 4H), 6.54 (d, J = 7.0 Hz, 2H), 6.45 (d, J = 7.5 Hz, 2H), 5.70 (d, J = 2.3 Hz, 1H), 5.67 (d, J = 3.8 Hz, 1H), 5.64-5.63 (m, 2H), 5.29 (dd, J = 8.7, 8.0 Hz, 1H), 5.19 (d, J = 8.5 Hz, 1H), 5.13 (d, J = 6.5 Hz, 2H), 5.07-5.00 (m, 4H), 4.95 (dd, J = 13.2, 6.5 Hz, 1H), 4.85-4.48 (m, 28H), 4.45-4.28 (m, 10H), 4.25-4.05 (m, 15H), 4.03-3.94 (m, 6H), 3.91-3.88 (m, 2H), 3.84-3.69 (m, 7H), 3.57-3.19 (m, 23H), 3.11 (d, J = 9.5 Hz, 2H), 2.86-2.84 (m, 1H), 1.54-1.44 (m, 4H), 1.27 (d, J = 6.5 Hz, 3H), 1.11 (d, J = 6.5 Hz, 3H), 0.98 (d, J = 6.5 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 168.33, 168.31,166.73, 166.69, 166.52, 165.91, 163.92, 156.66, 156.10, 139.36, 138.99, 138.69, 138.44, 138.41, 138.32, 138.23, 138.15, 138.09, 138.05, 137.99, 137.91, 137.88, 137.83, 137.61, 137.54, 137.33, 136.84, 136.75, 133.56, 133.07, 132.88, 132.44, 132.32, 131.68, 131.04, 130.53, 130.25, 130.20, 129.96, 129.94, 129.86, 129.74, 129.72, 129.48, 129.39, 128.55, 128.53, 128.47, 128.43, 128.38, 128.35, 128.33, 128.21, 128.20, 128.15, 128.12, 128.06, 128.02, 127.99, 127.94, 127.87, 127.86, 127.82, 127.78, 127.77, 127.74, 127.69, 127.67, 127.64, 127.60, 127.54, 127.50, 127.46, 127.43, 127.37, 127.32, 127.29, 127.27, 127.24, 127.18, 127.13, 127.00, 126.99, 126.92, 126.90, 126.86, 126.70, 126.22, 126.14, 123.26, 103.45, 102.59, 100.12, 99.93, 99.91, 99.59, 98.41, 98.20, 97.92, 83.90, 82.86, 81.81, 81.54, 80.05, 78.30, 77.42, 76.68, 76.06, 75.95, 75.81, 75.37, 74.98, 74.85, 74.62, 74.21, 74.11, 73.92, 73.72, 73.65, 73.52, 73.32, 73.23, 73.15, 73.12, 72.91, 72.87, 72.84, 72.76, 72.58, 72.50, 72.47, 71.98, 71.75, 71.71, 71.60, 71.56, 71.48, 71.23, 71.17, 71.08, 71.01, 69.63, 69.49, 68.21, 68.02, 67.74, 67.61, 67.59, 67.09, 65.27, 65.23, 65.22, 56.93, 56.76, 50.50, 50.19, 47.12, 46.16, 29.33, 27.88, 27.48, 23.31, 15.94, 15.85, 15.43. HRMS (ESI): $[M + 2NH_4]^{2+}$ $C_{251}H_{259}N_5O_{51}^{2+}$ m/z calcd. 2079.3908, found 2079.3927.

5.7 Synthesis of compound **1**



Compound **2** (40.0 mg, 9.7 μmol) was dissolved in $H_2NCH_2CH_2NH_2$/*n*-BuOH (v/v = 1:3, 20 mL). The solution was heated at 120 °C for 6 h. The solution was concentrated under reduced pressure. The residue was dissolved in MeOH (5.0 mL), then Ac_2O (1.0 mL) was added, and the reaction was performed at room temperature for 3 h. The solution was concentrated under reduced pressure and fully dried under

vacuum. The residue was dissolved in THF/MeOH (v/v = 1:4, 5 mL), then LiOH (50.0 mg, 1.2 mmol) was added. The solution was heated at 80 °C overnight. H^+ resin was used for neutralization. The mixture was filtered and the filtrate was concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (toluene: CH_3CN = 6:1, v/v) to afford white solids. The obtained product was dissolved in CH_2Cl_2/MeOH/H_2O (v/v, 3:3:1, 7 mL), then $Pd(OH)_2$ (10%, 15.0 mg) was added. The reaction was carried out under a hydrogen atmosphere of 40 psi for 30 h. The mixture was filtered and the filtrate was concentrated under reduced pressure. The residue was purified by column chromatography on gel LH20 (H_2O: MeOH = 15:1, v/v) to afford **1** as white solids (10.0 mg, 63% yield). ^{1}H NMR (400 MHz, D_2O) δ 5.19 (d, *J* = 3.1 Hz, 1H), 5.03 (t, *J* = 3.6 Hz, 2H), 4.83-4.76 (m, 1H), 4.62 (d, *J* = 8.0 Hz, 2H), 4.45-4.31 (m, 4H), 4.19-4.11 (m, 1H), 4.07 (d, *J* = 3.3 Hz, 1H), 4.00 (d, *J* = 3.3 Hz, 1H), 3.95-3.30 (m, 46H), 3.24-3.16 (m, 1H), 2.92 (d, *J* = 7.5 Hz, 2H), 1.93 (s, 6H), 1.65-1.54 (m, 4H), 1.43-1.30 (m, 2H), 1.17 (d, *J* = 6.6 Hz, 3H), 1.15 (d, *J* = 6.7 Hz, 3H), 1.06 (d, *J* = 6.5 Hz, 3H). ^{13}C NMR (151 MHz, D_2O) δ 174.70, 174.66, 102.95, 102.50, 102.42, 101.99, 101.72, 100.20, 99.43, 98.69, 98.58, 82.08, 81.55, 78.40, 76.38, 75.32, 75.11, 74.86, 74.77, 74.45, 73.56, 73.04, 72.80, 71.94, 71.85, 71.70, 70.56, 70.08, 69.94, 69.73, 69.17, 68.75, 68.28, 68.21, 67.70, 67.65, 66.92, 66.79, 66.69, 61.47, 61.41, 61.27, 61.11, 60.95, 60.08, 59.78, 59.65, 48.86, 39.36, 28.14, 26.43, 22.24, 22.07, 15.45, 15.43, 15.26. HRMS (ESI): $[M + H]^+$ $C_{63}H_{110}N_3O_{43}^+$ m/z calcd. 1596.6508, found 1596.6481.

6. References

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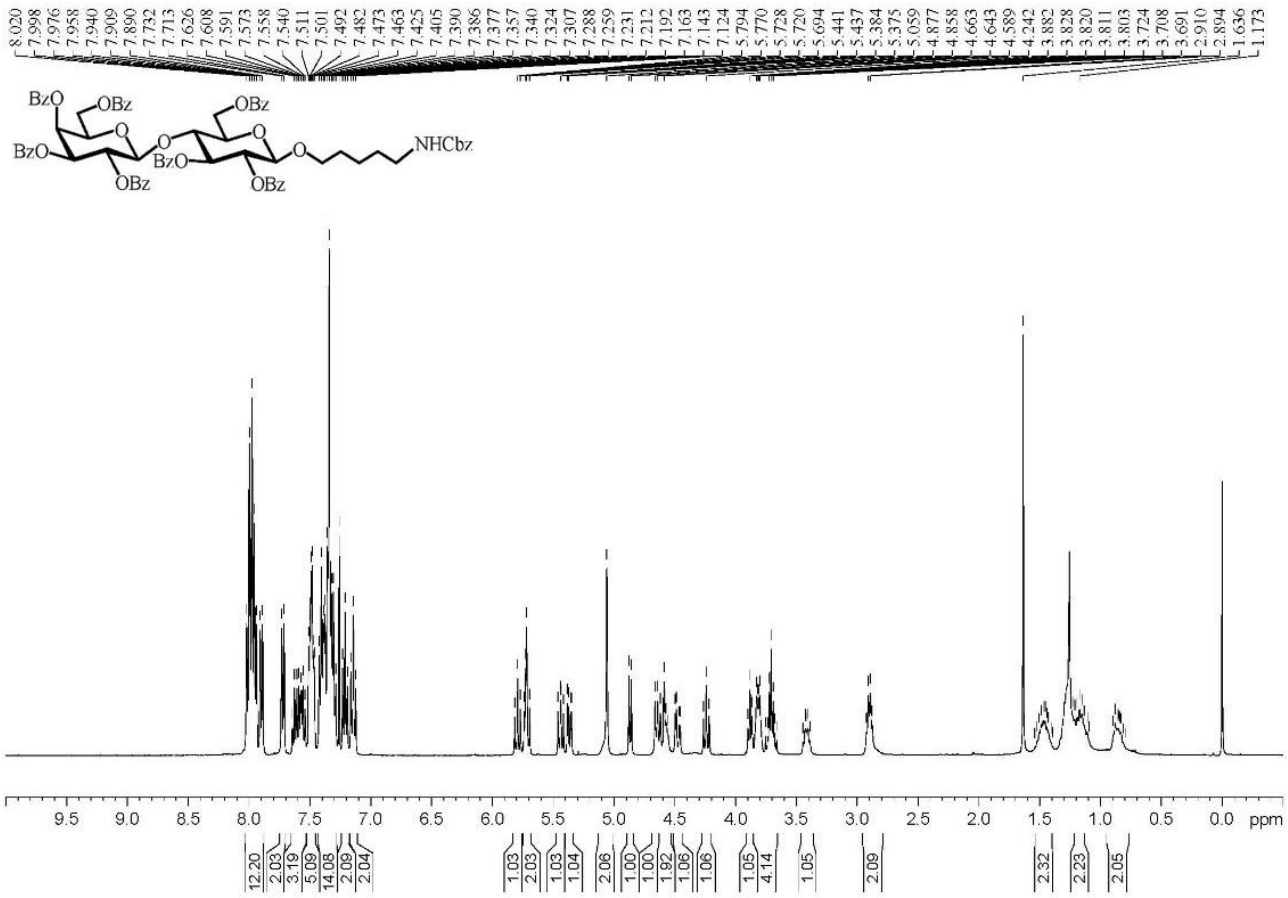
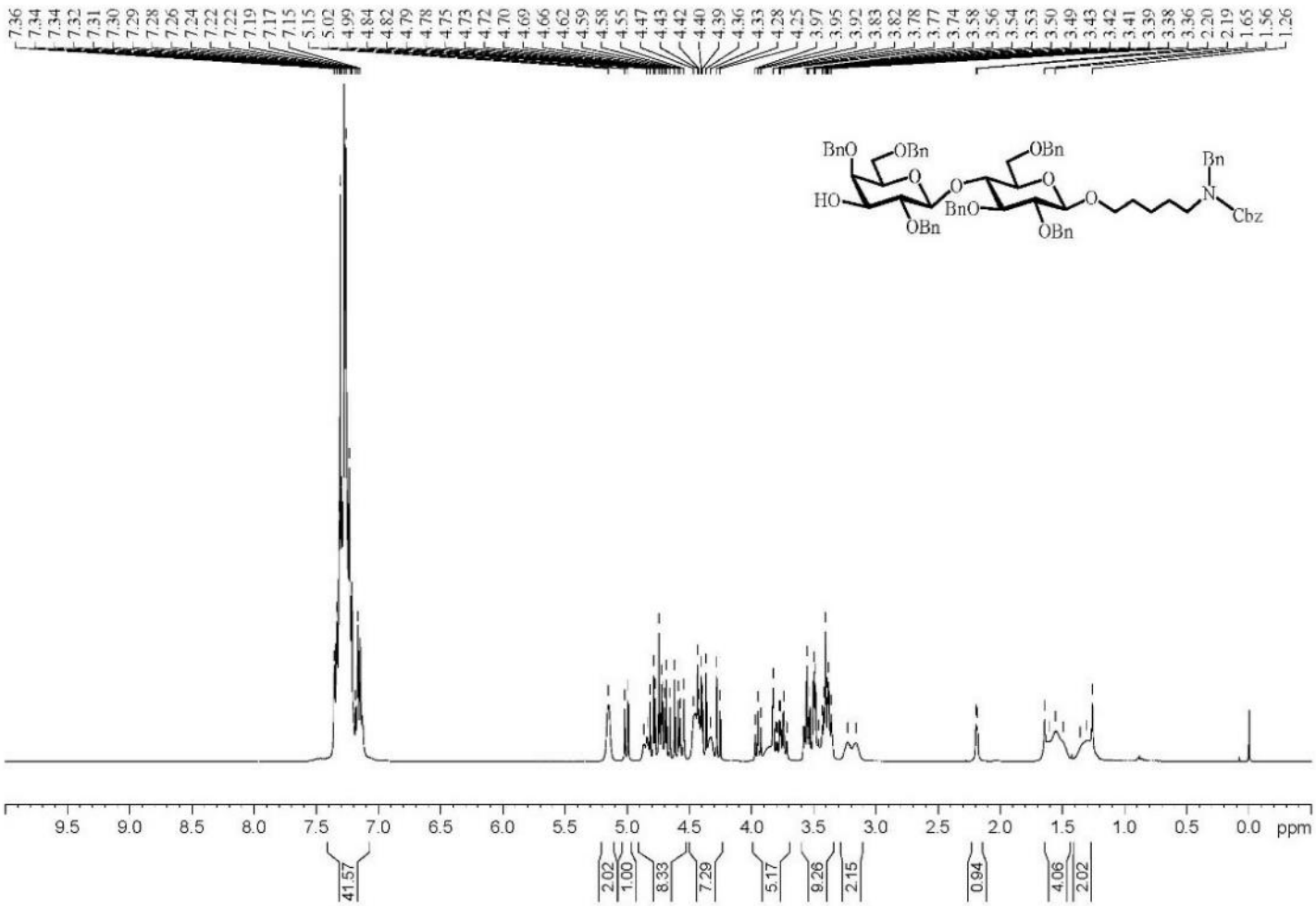
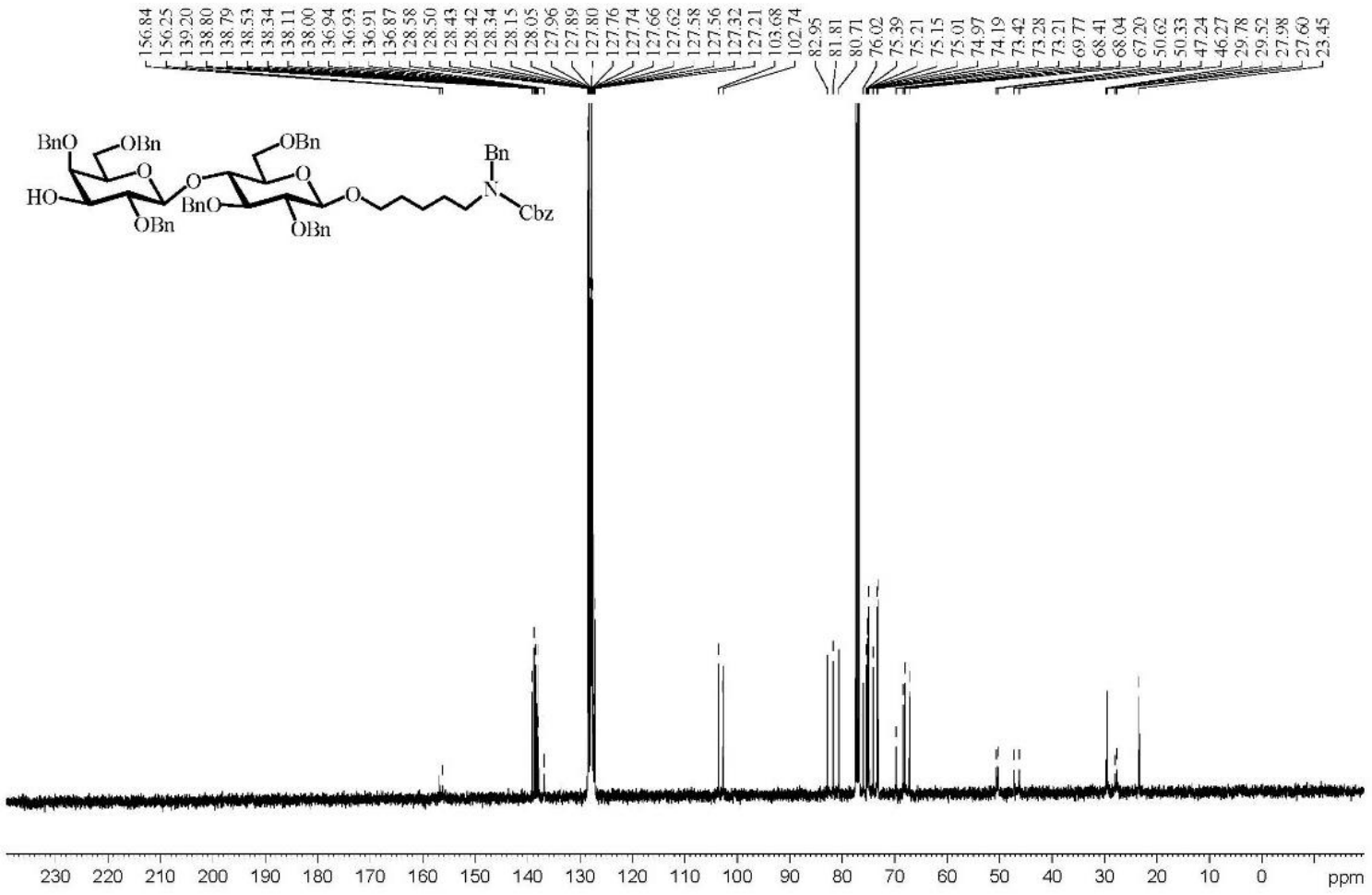
7. NMR Spectral Data



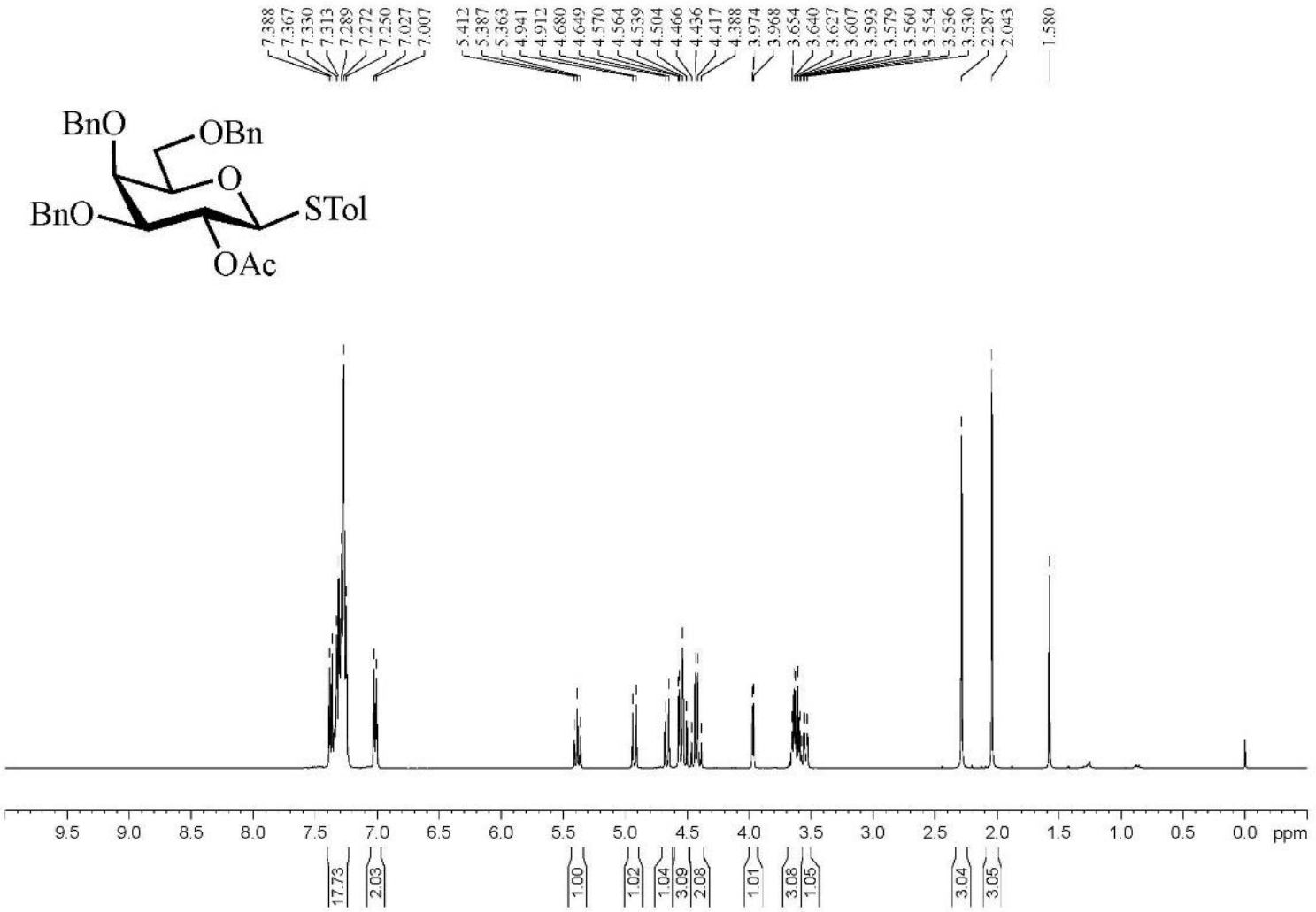
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 10



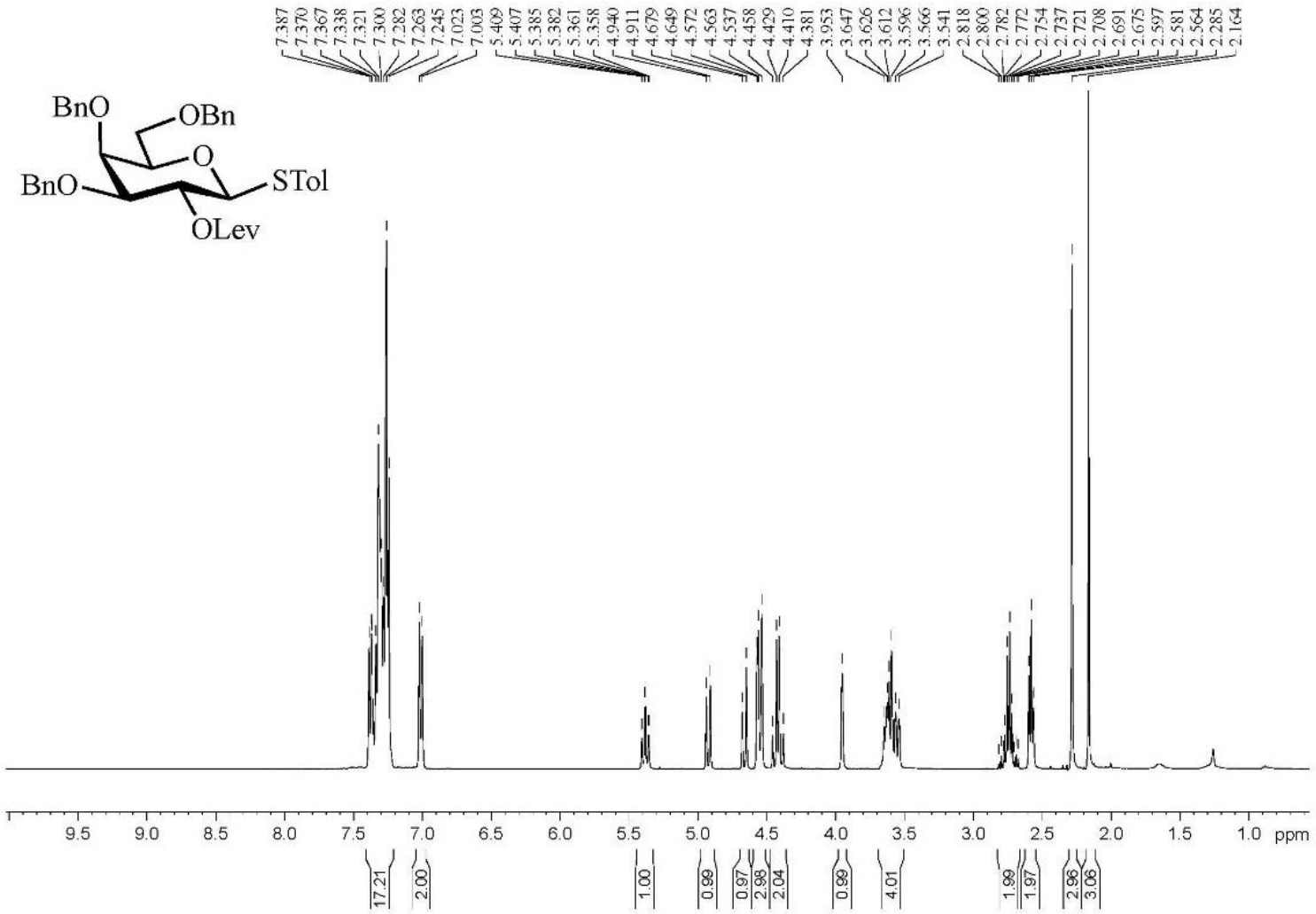
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 6



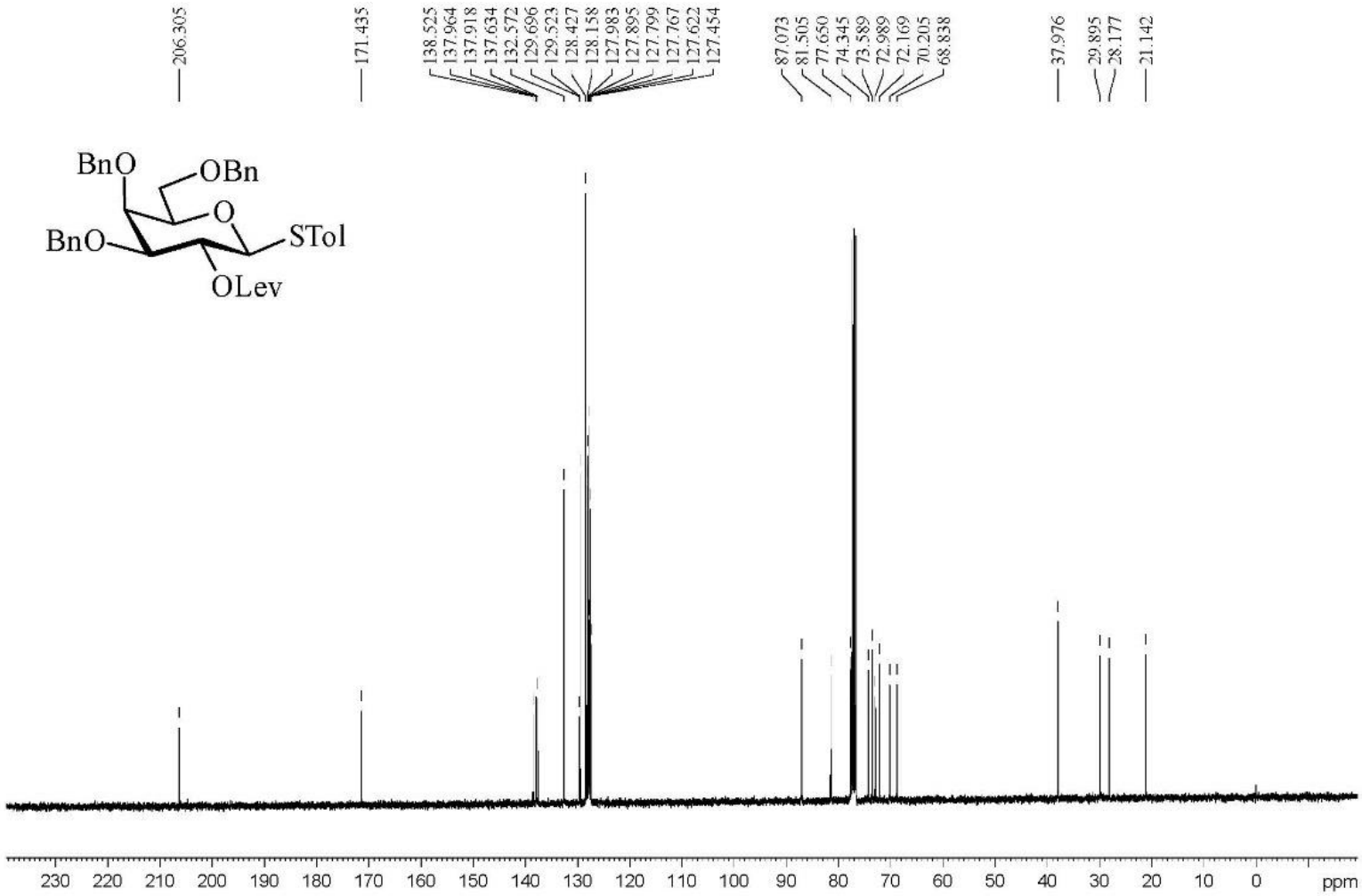
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 6



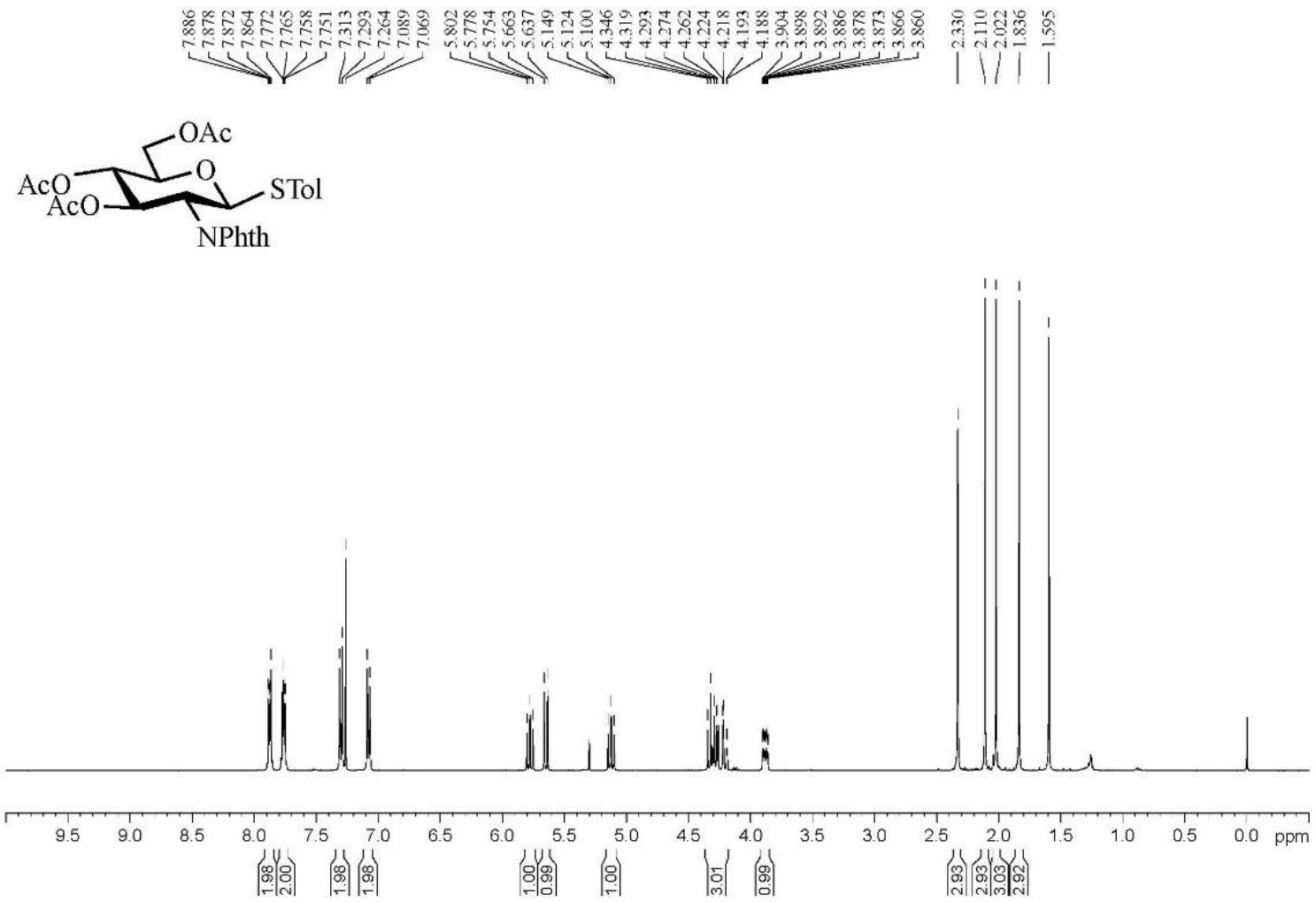
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound S5



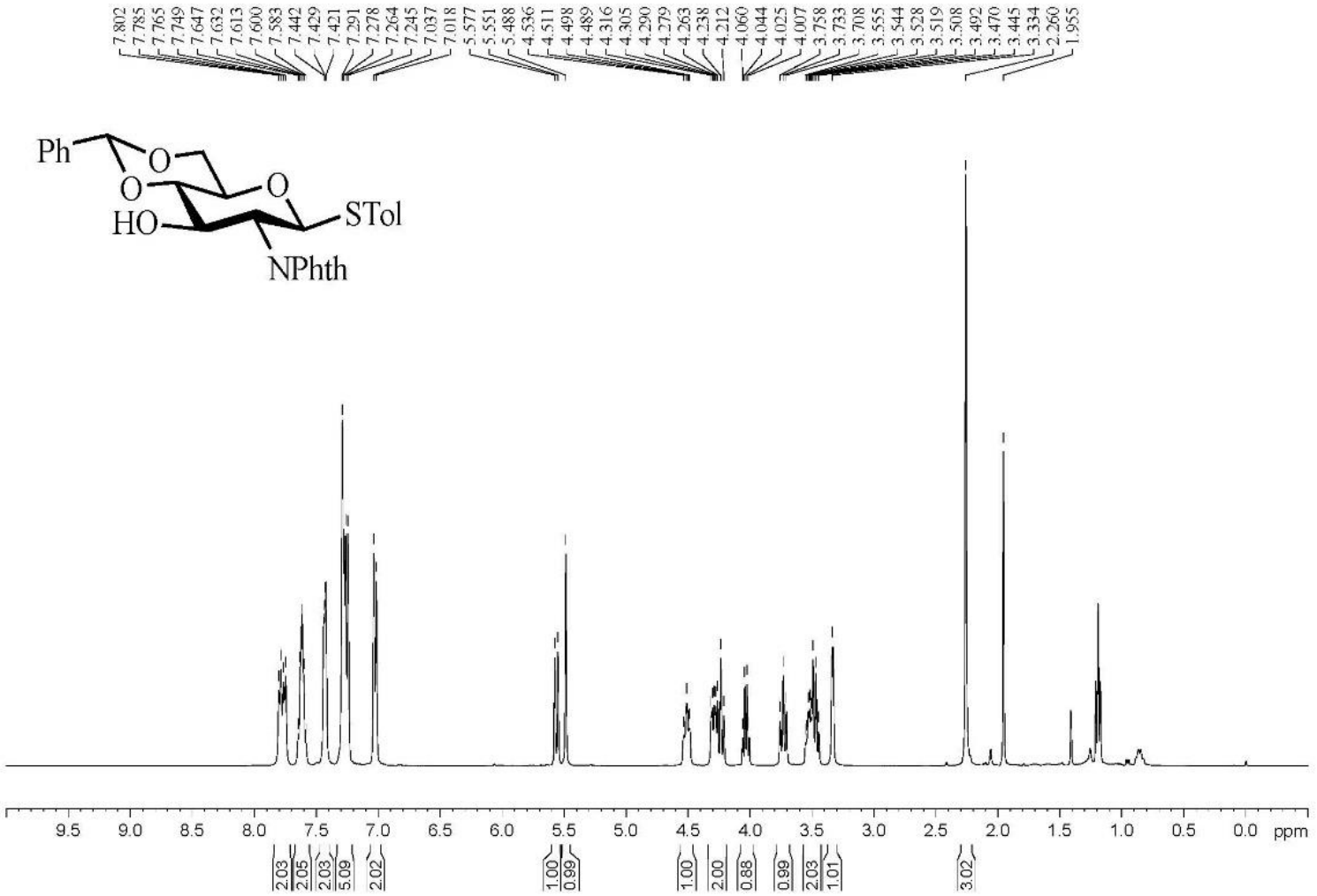
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 7



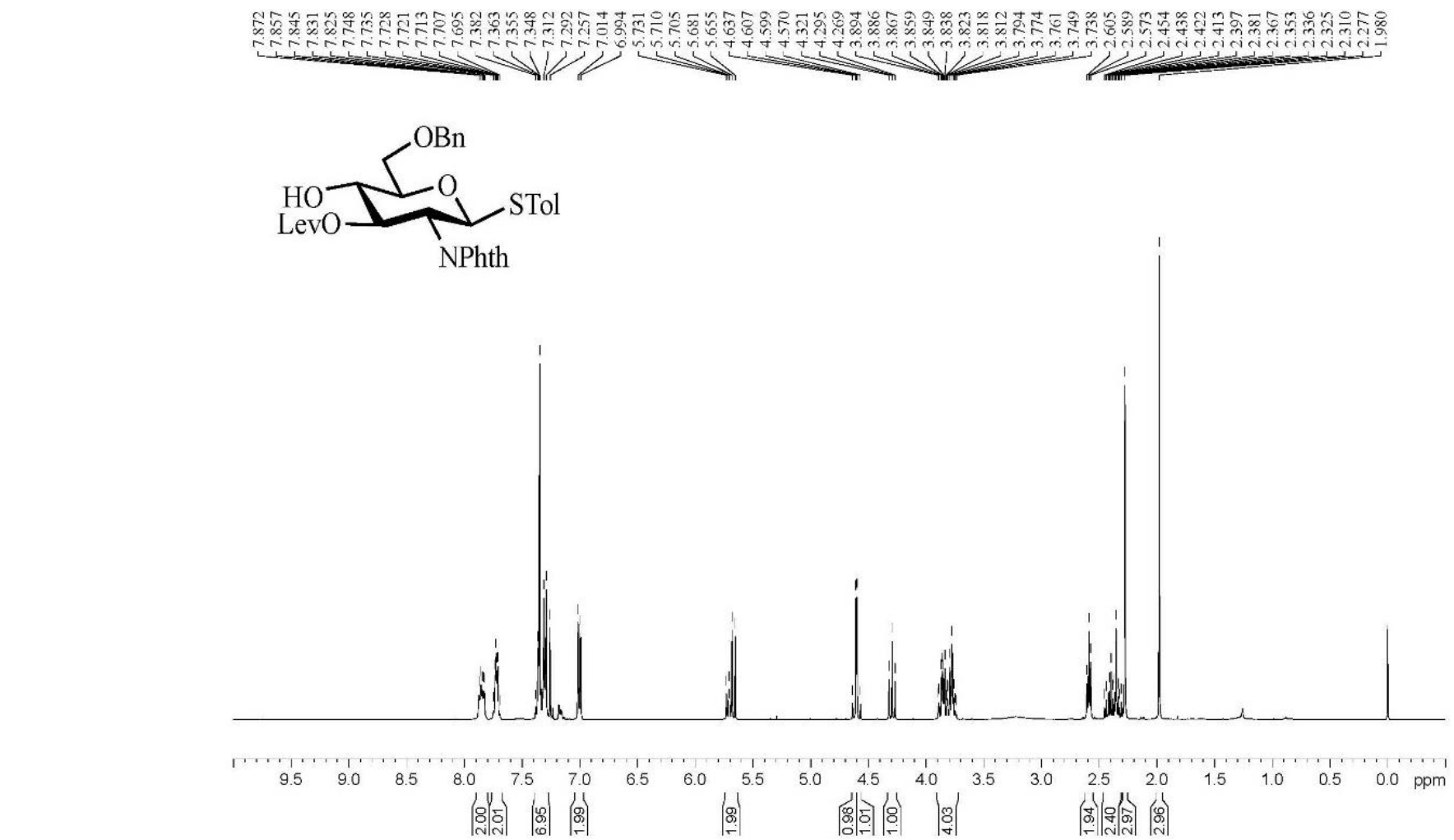
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 7



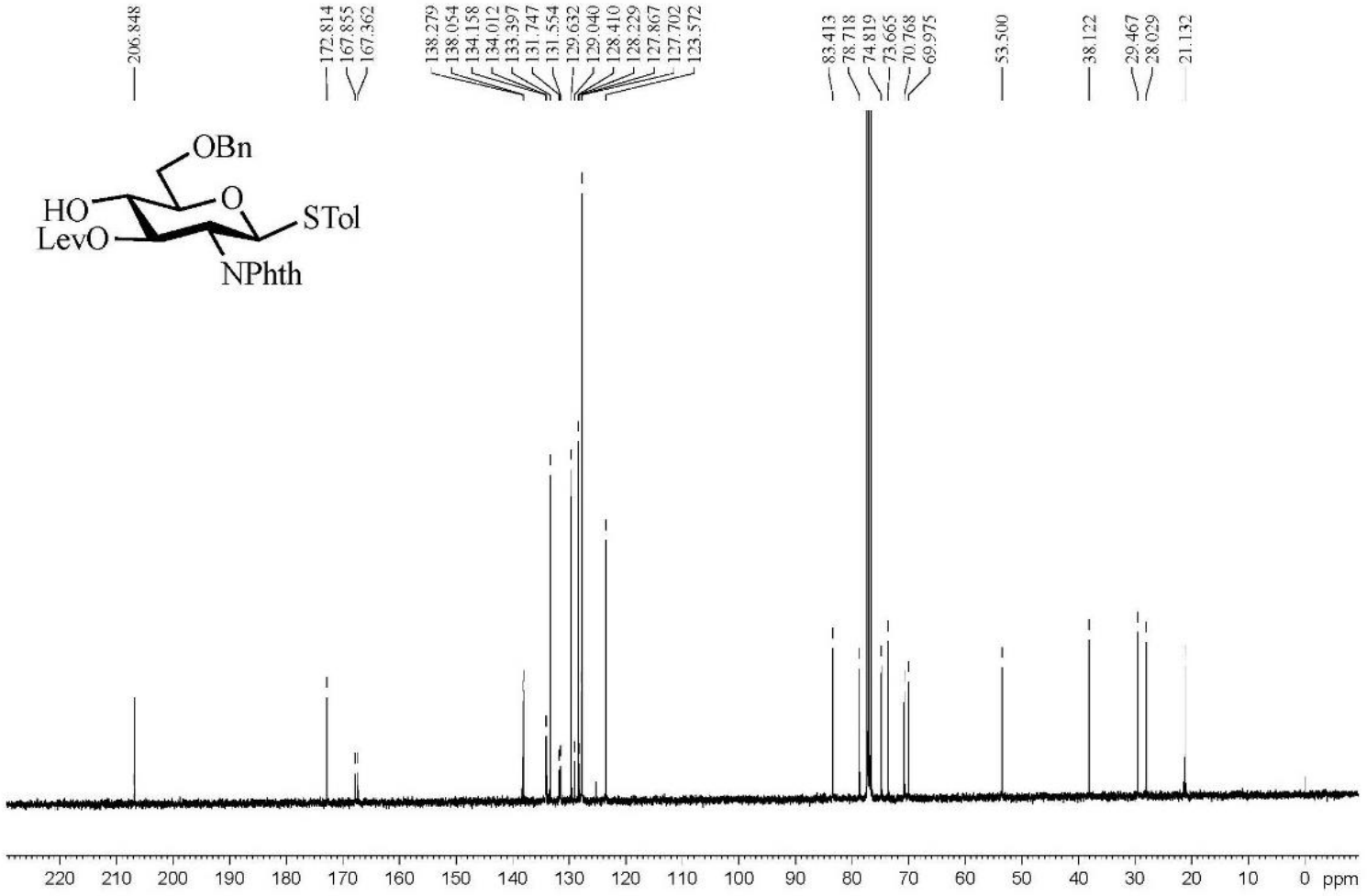
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound S6



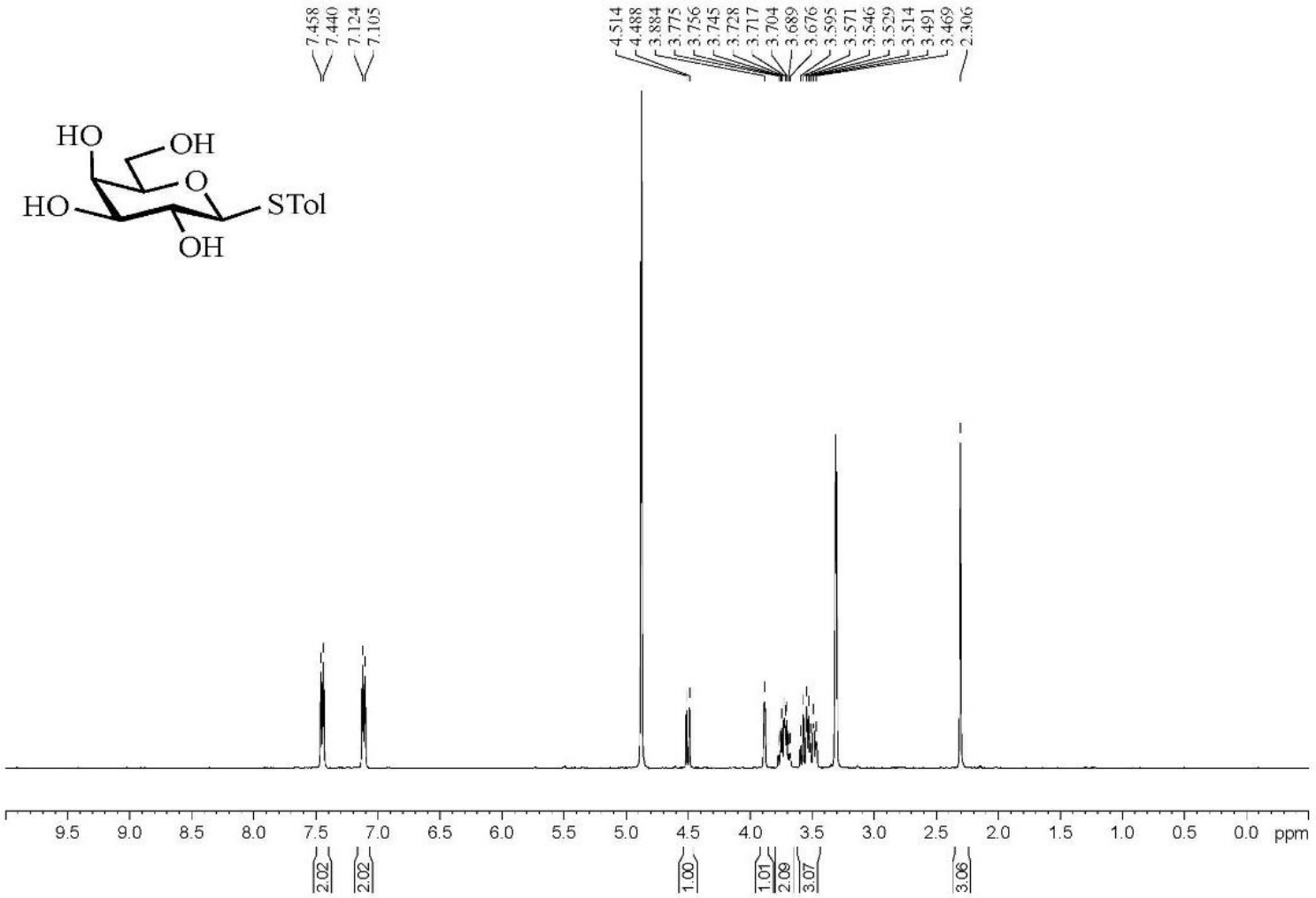
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 12



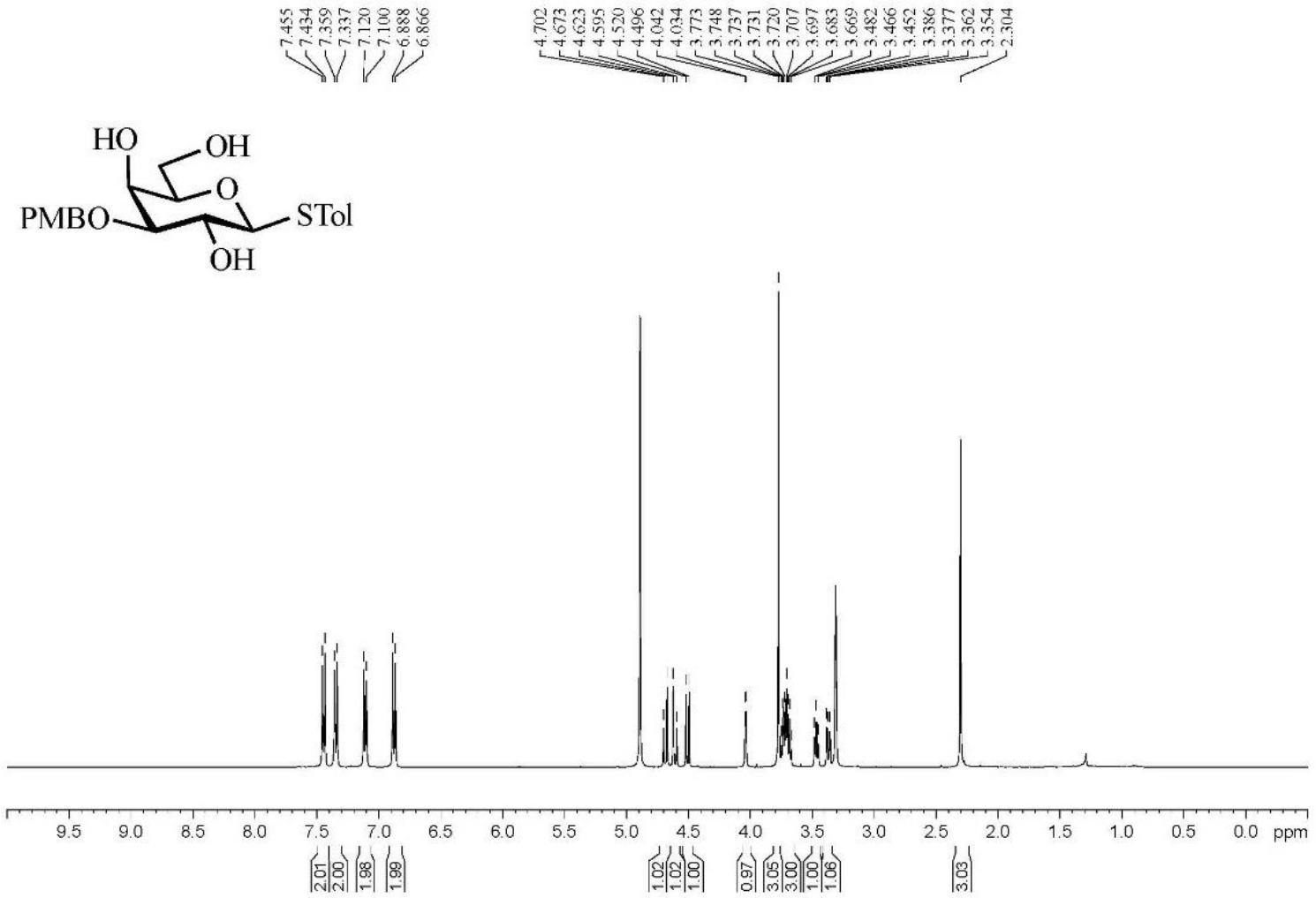
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 8



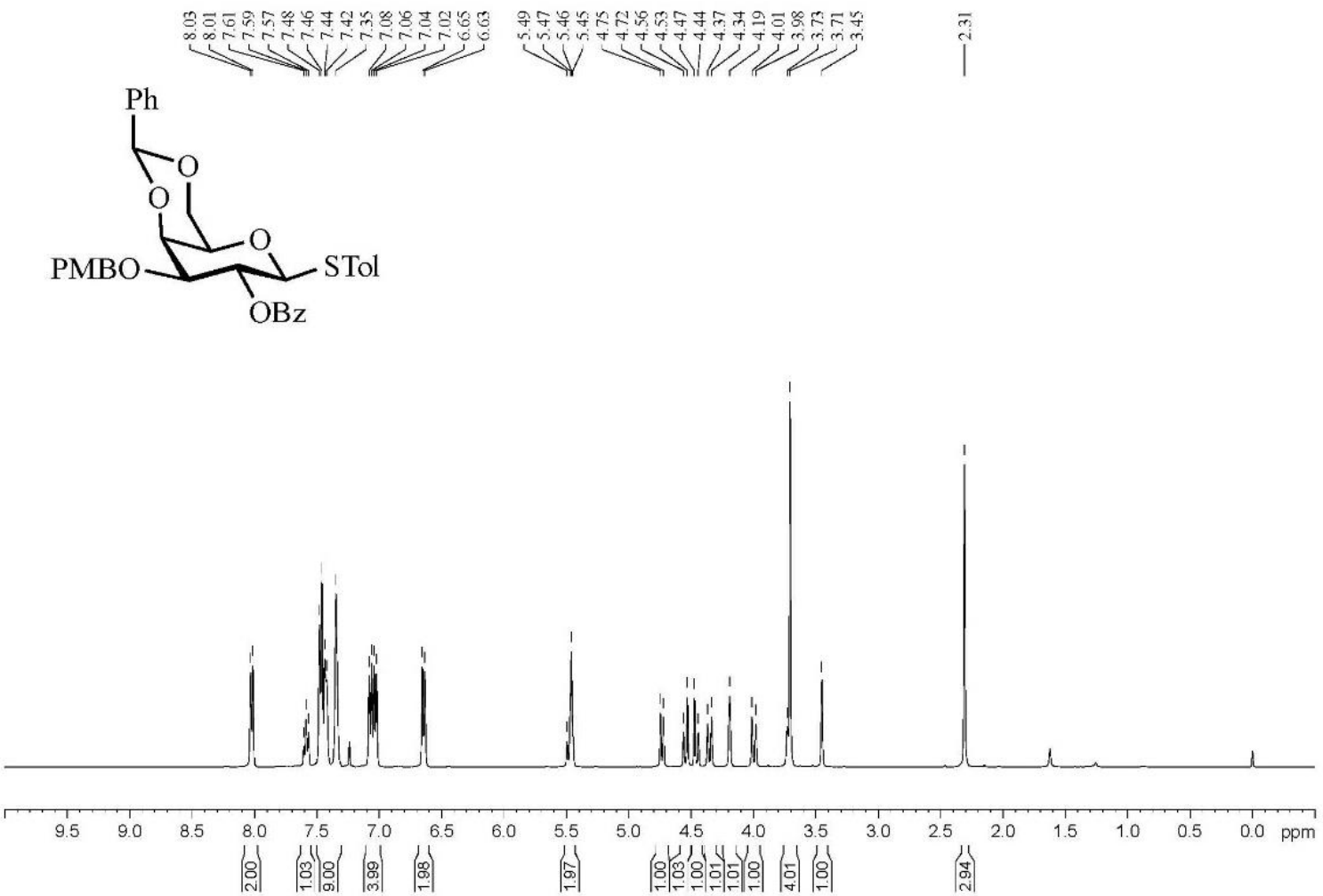
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 8



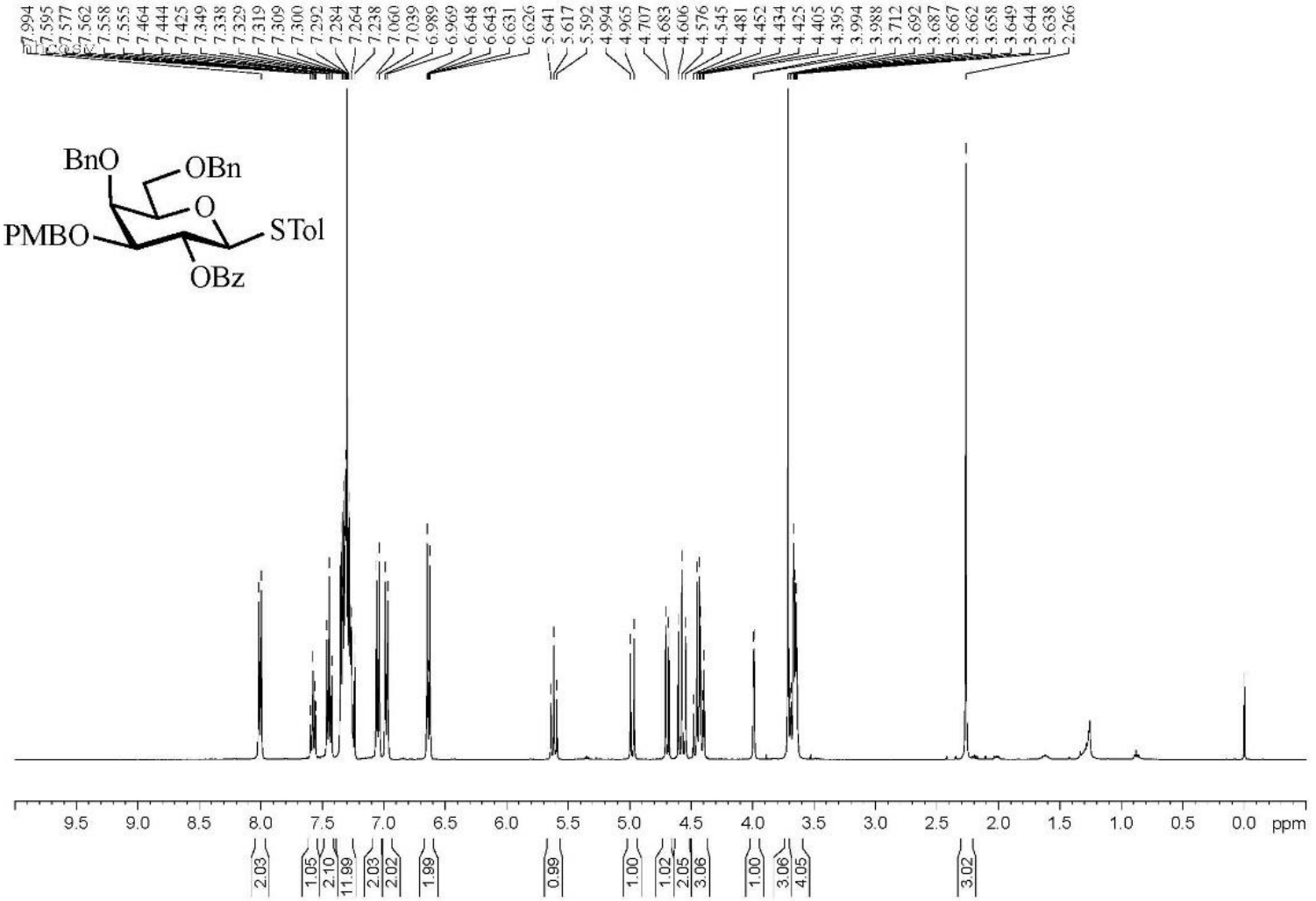
^{1}H NMR (400 MHz, CD_3OD) spectrum of compound S7



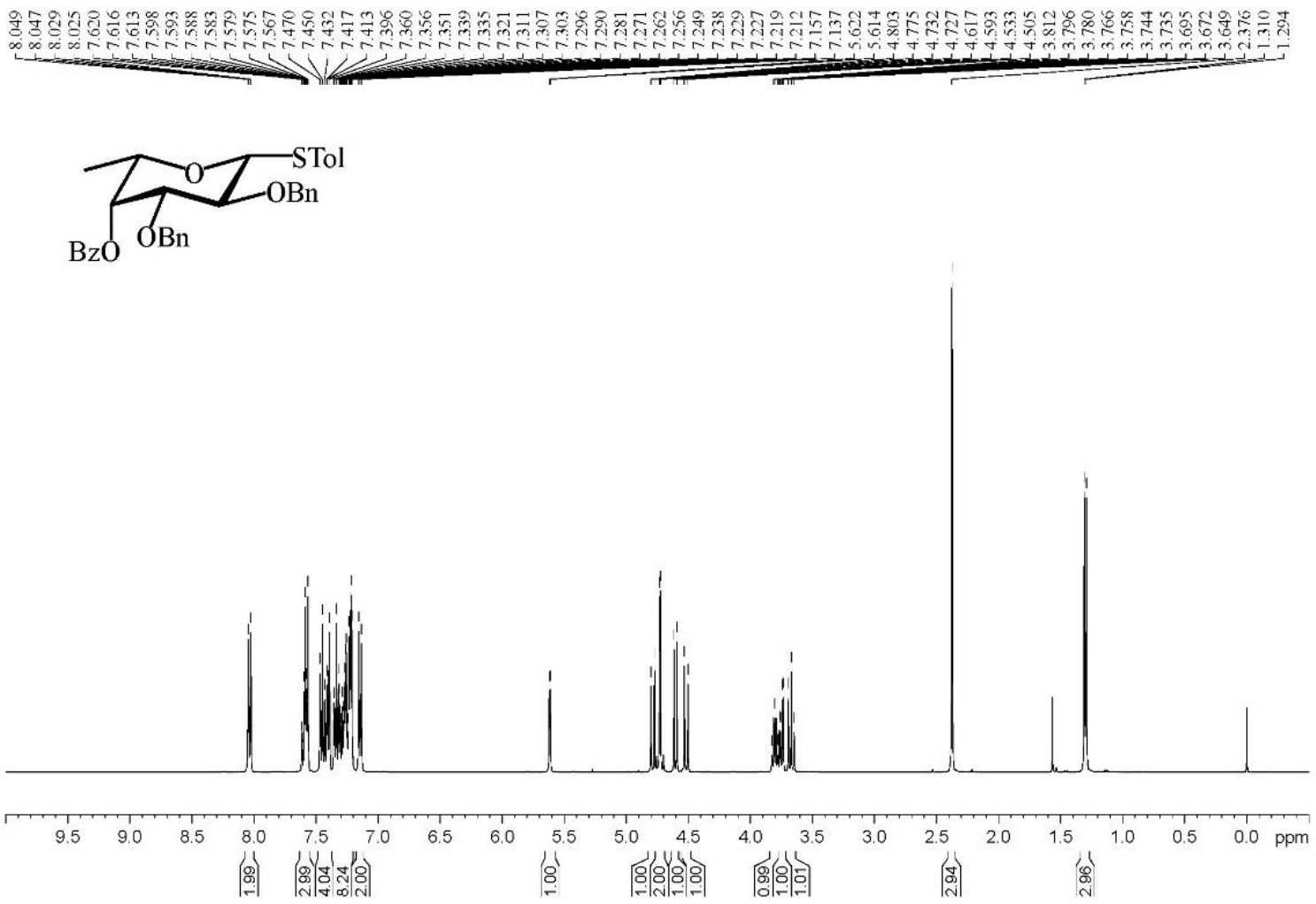
^{1}H NMR (400 MHz, CD_3OD) spectrum of compound S8



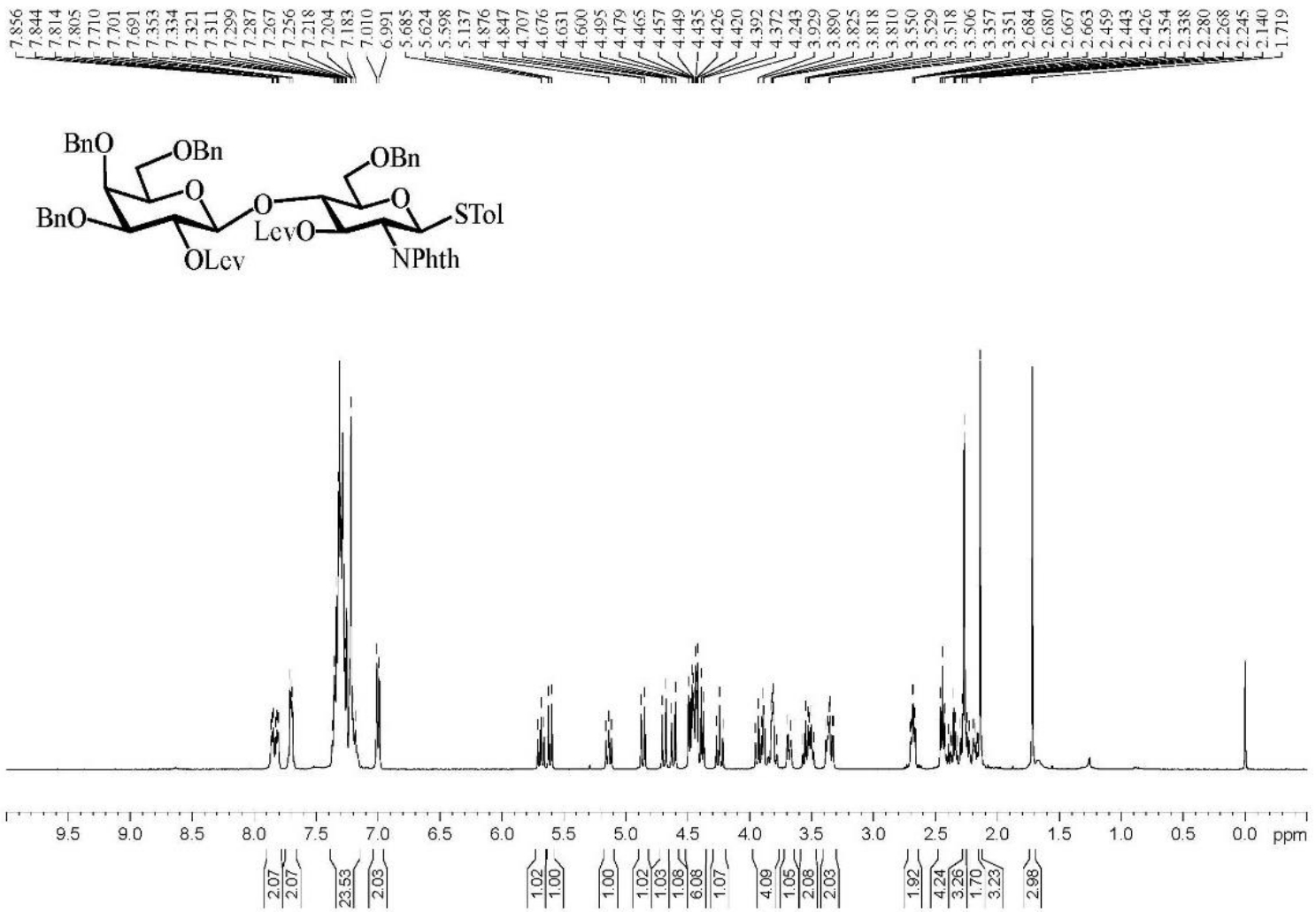
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound S9



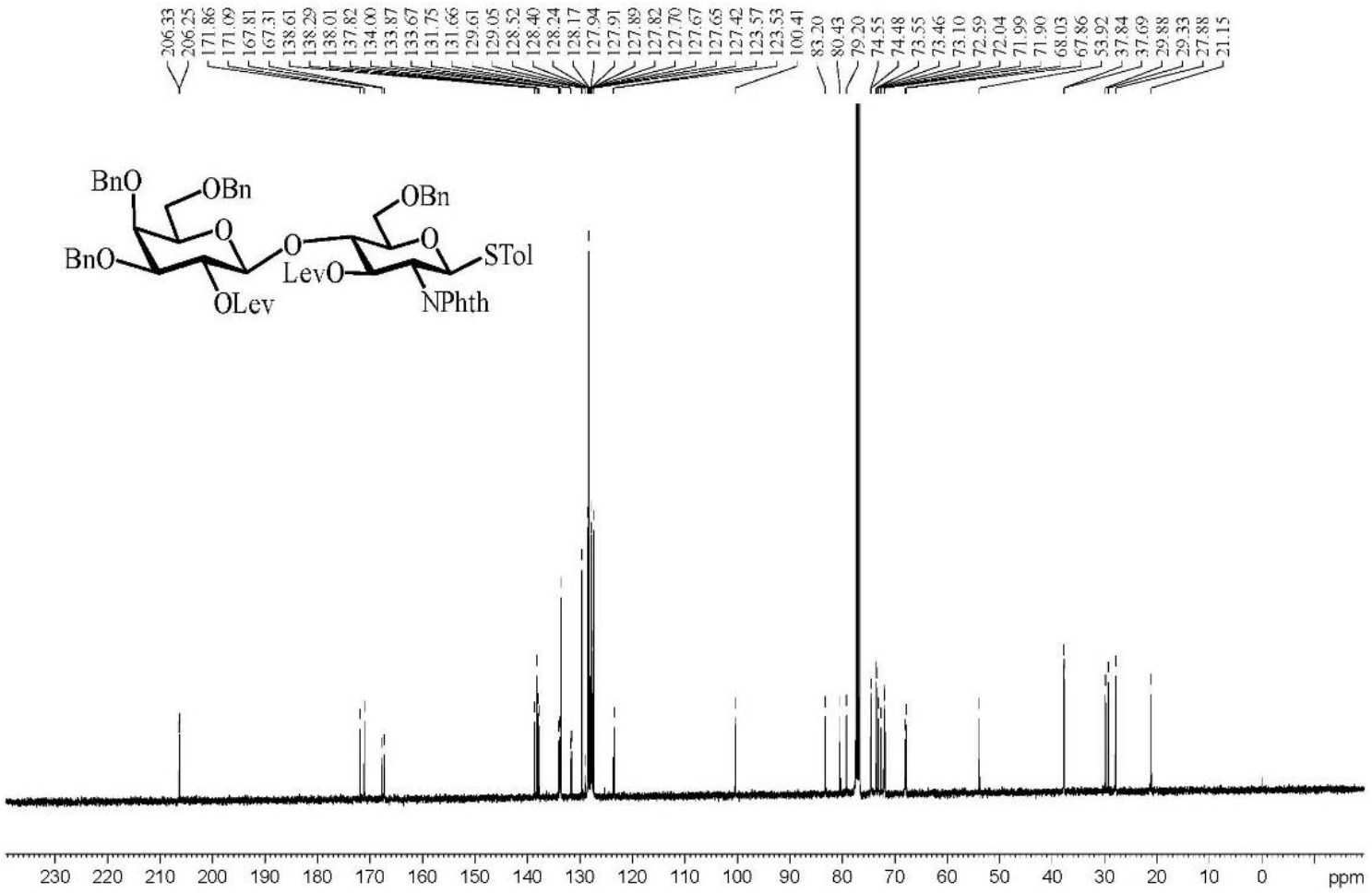
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 9



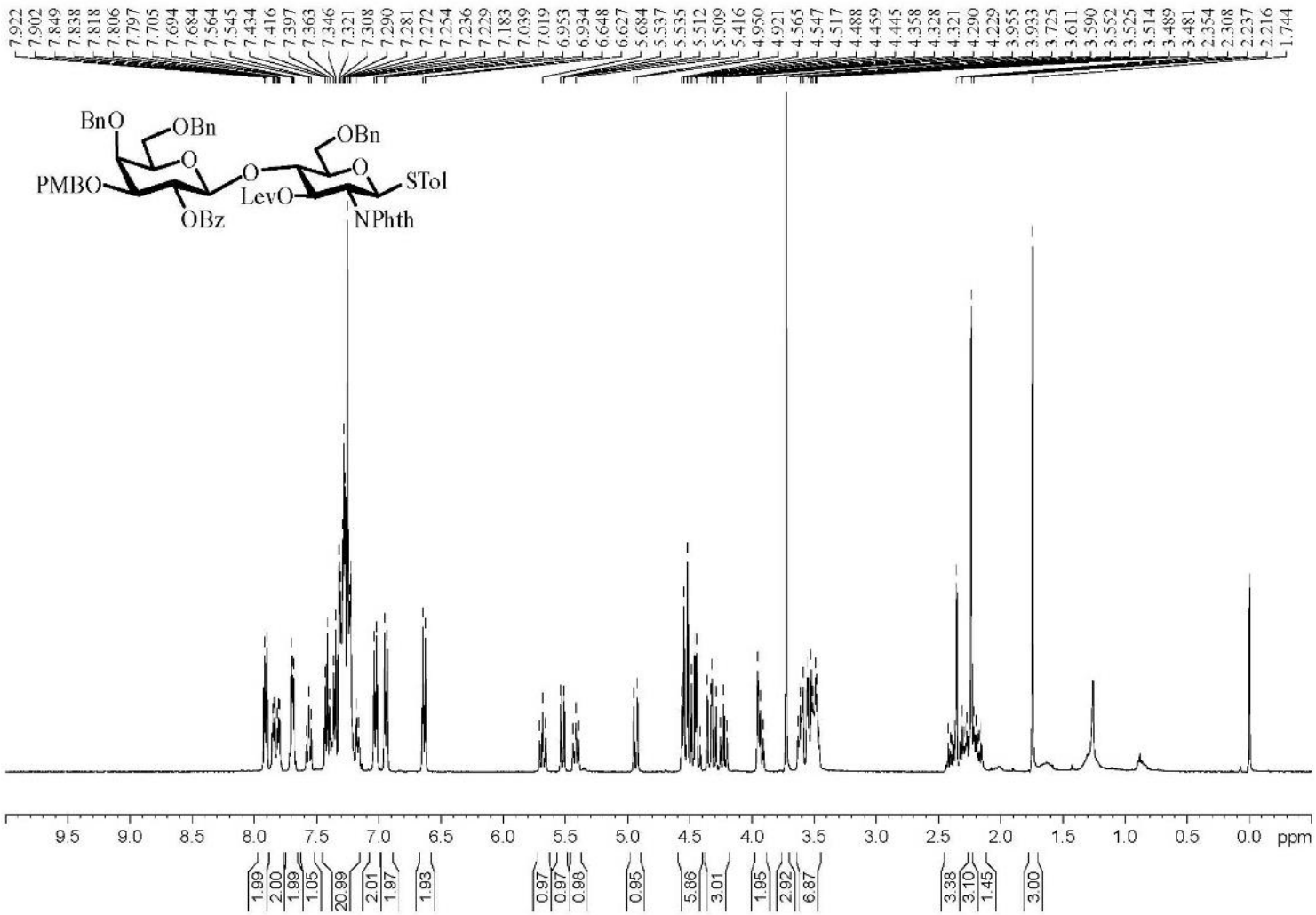
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 11



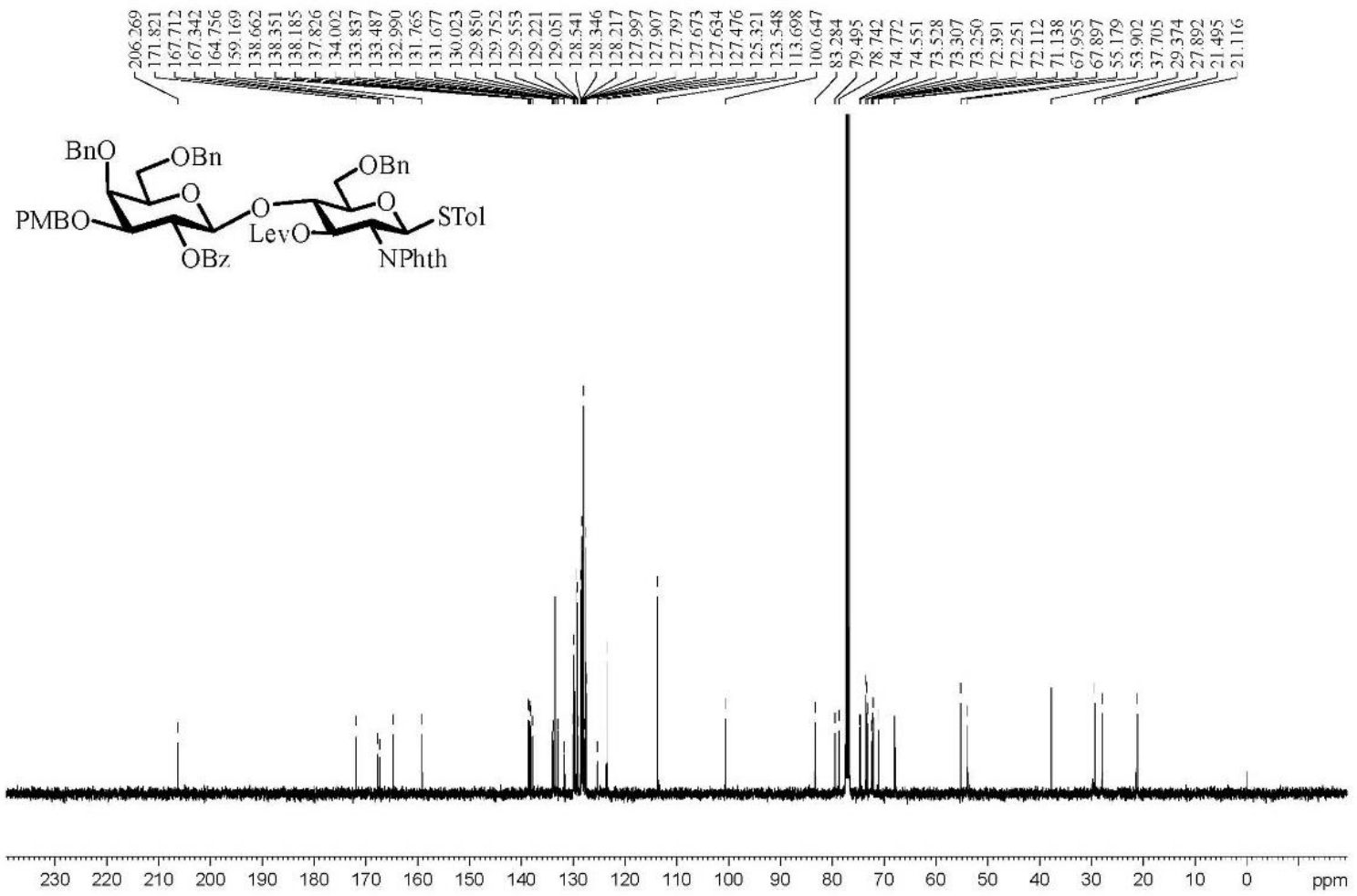
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 4



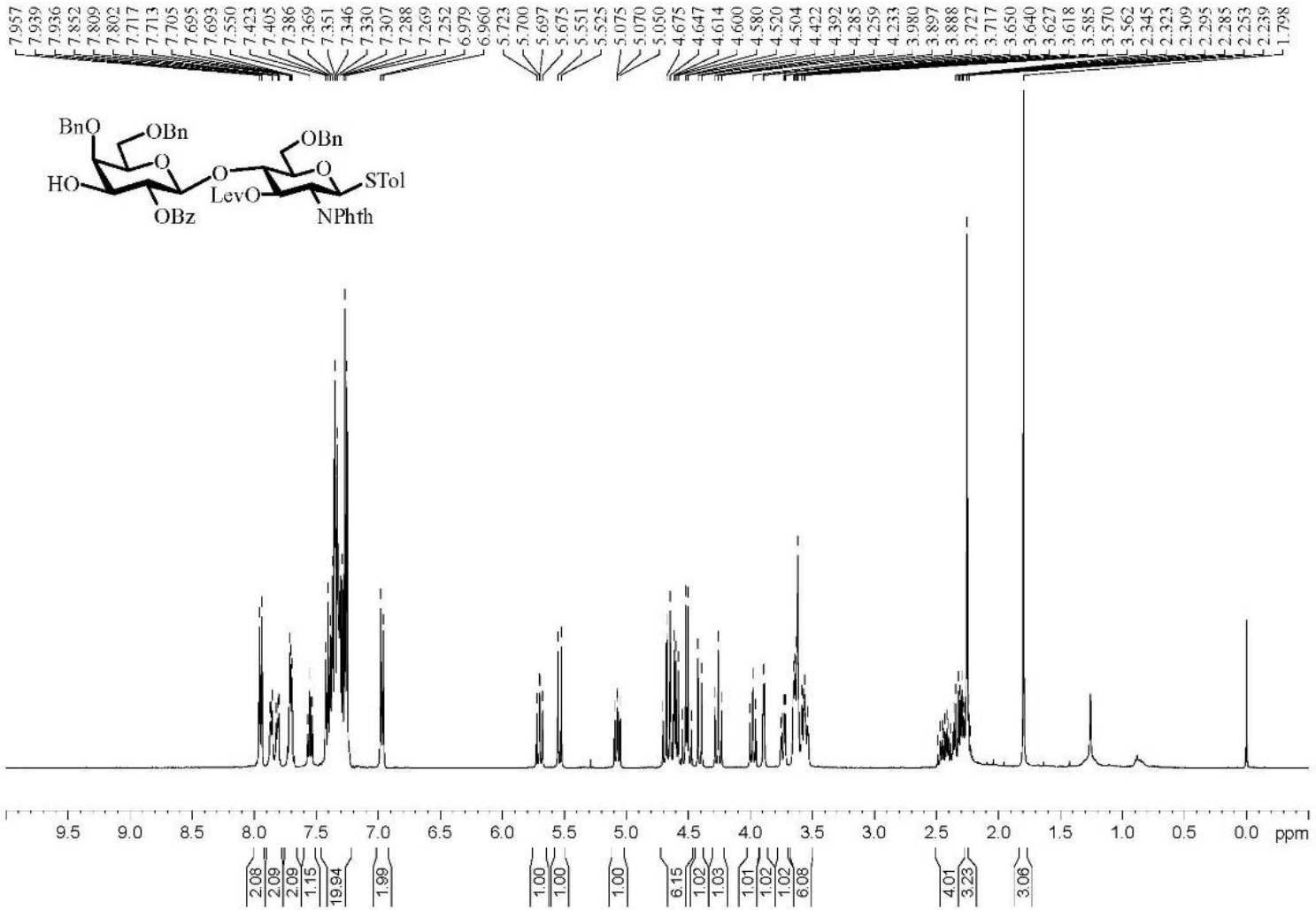
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 4



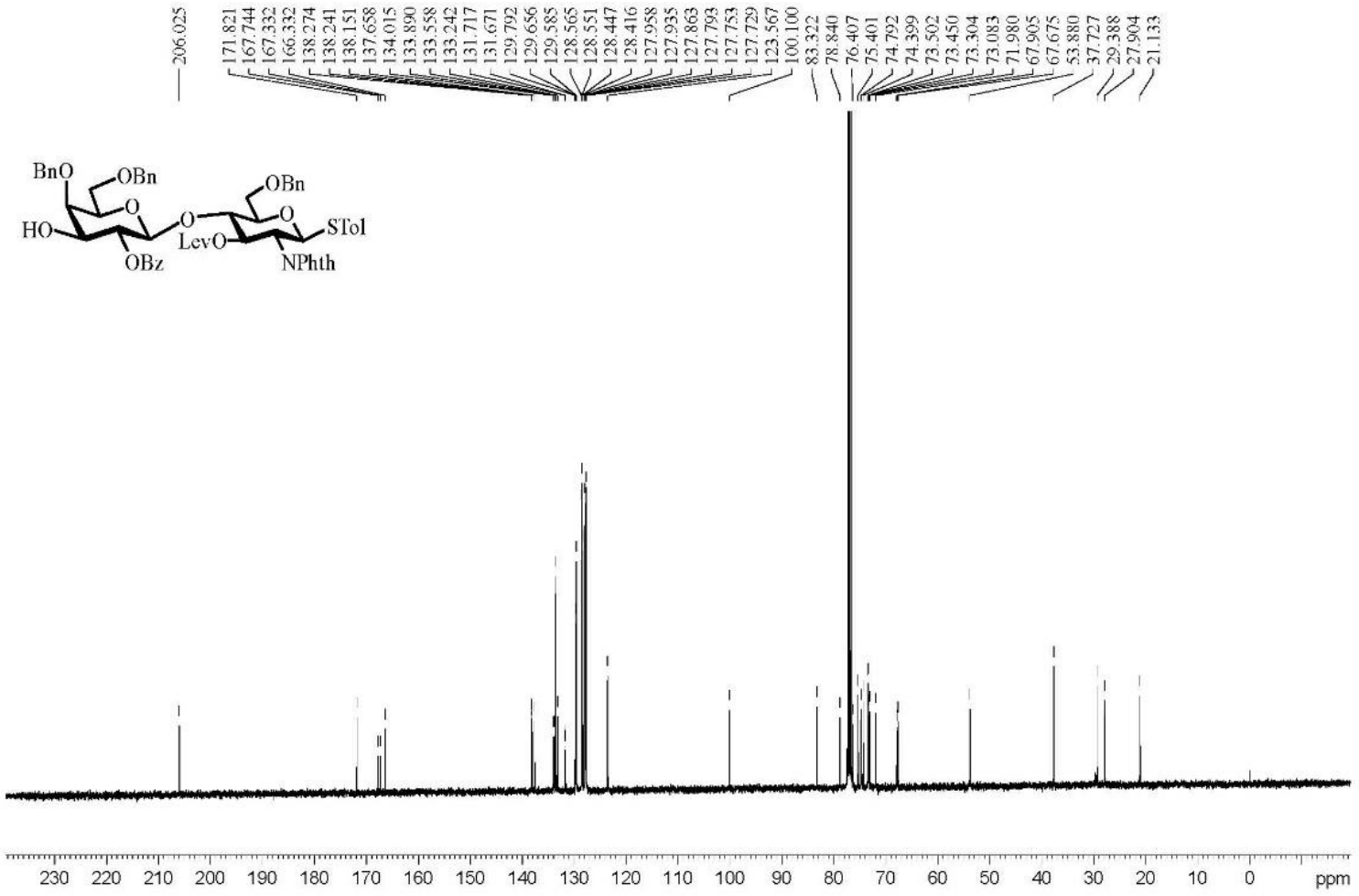
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 15



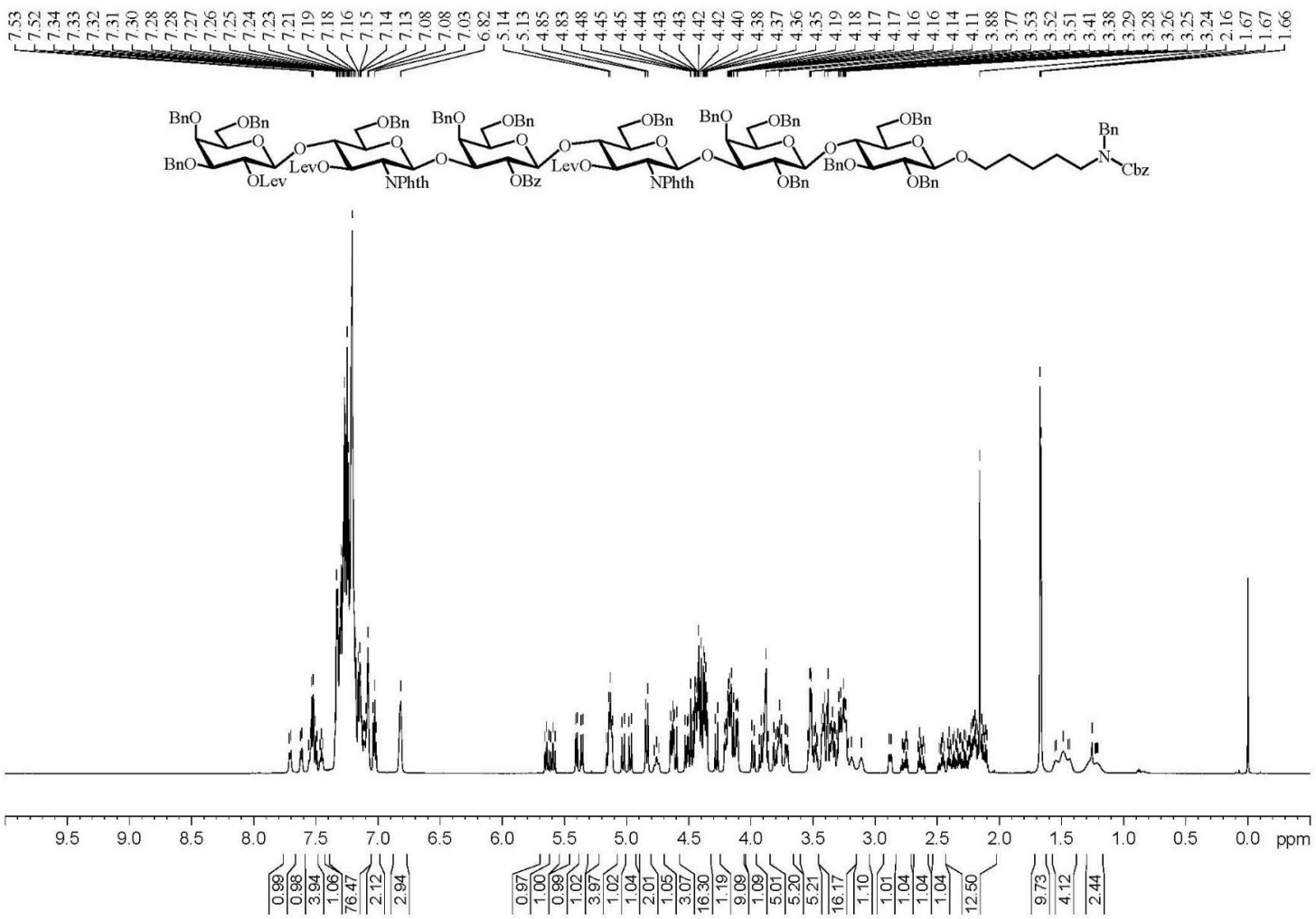
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 15



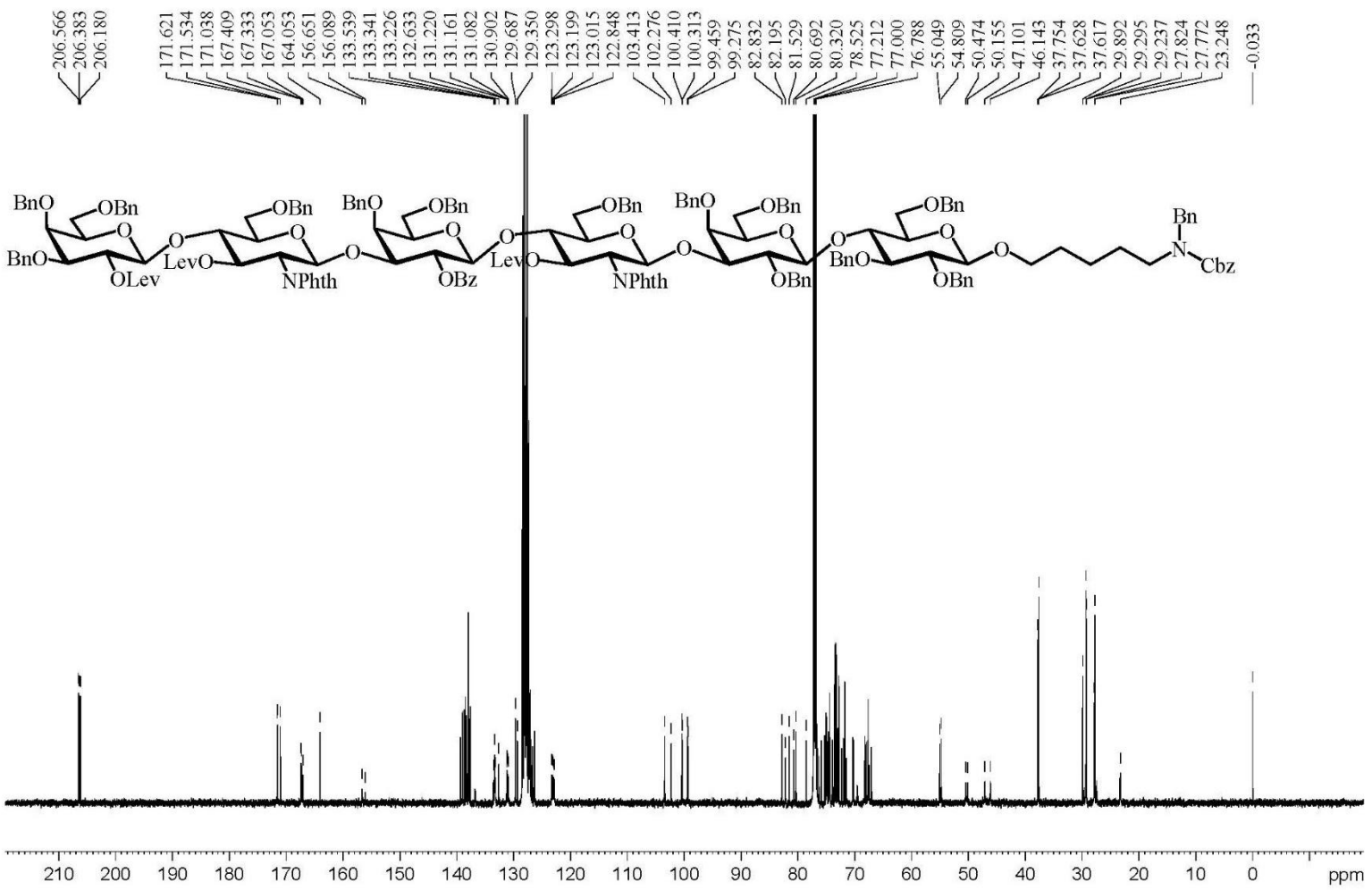
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 5



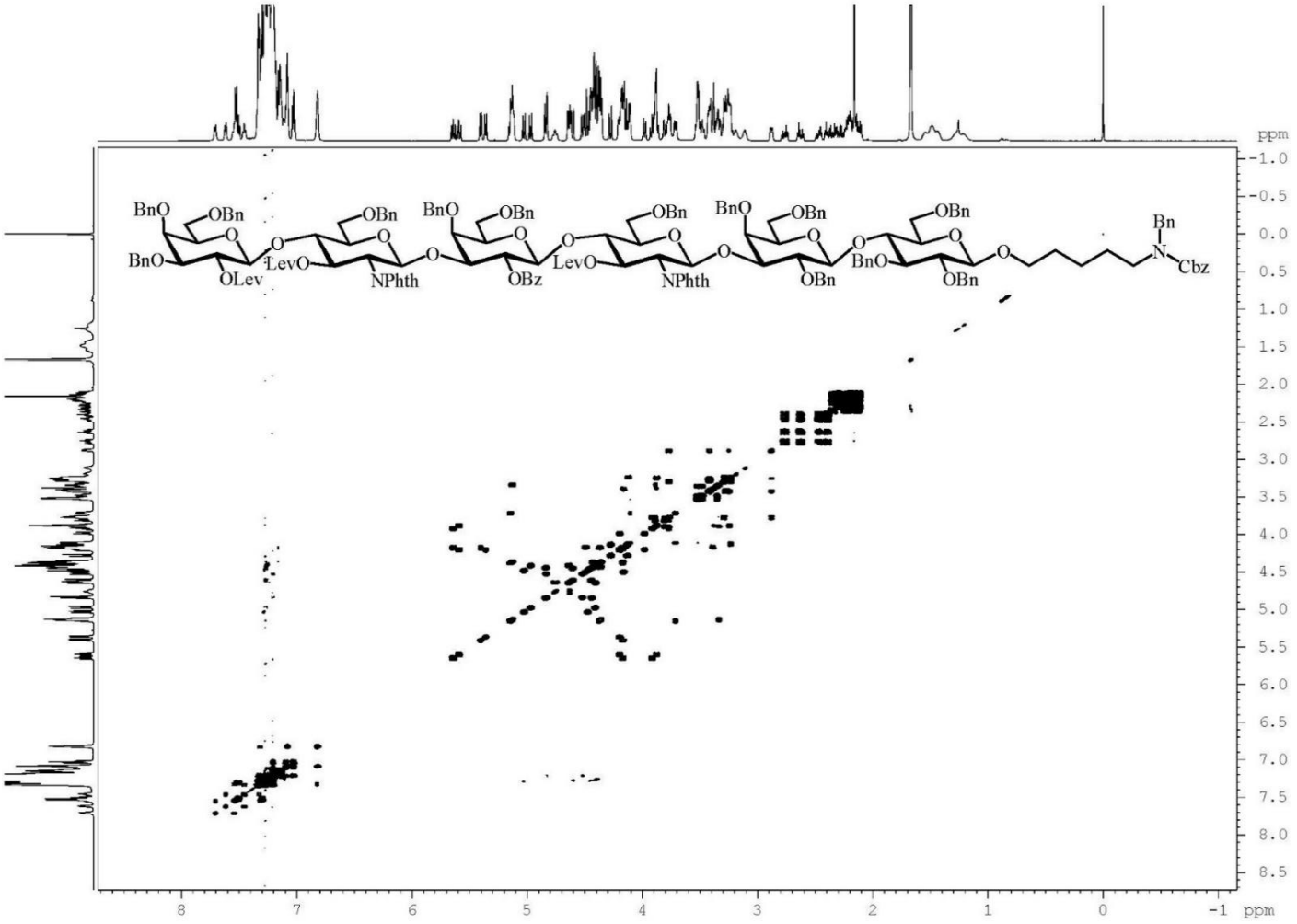
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 5



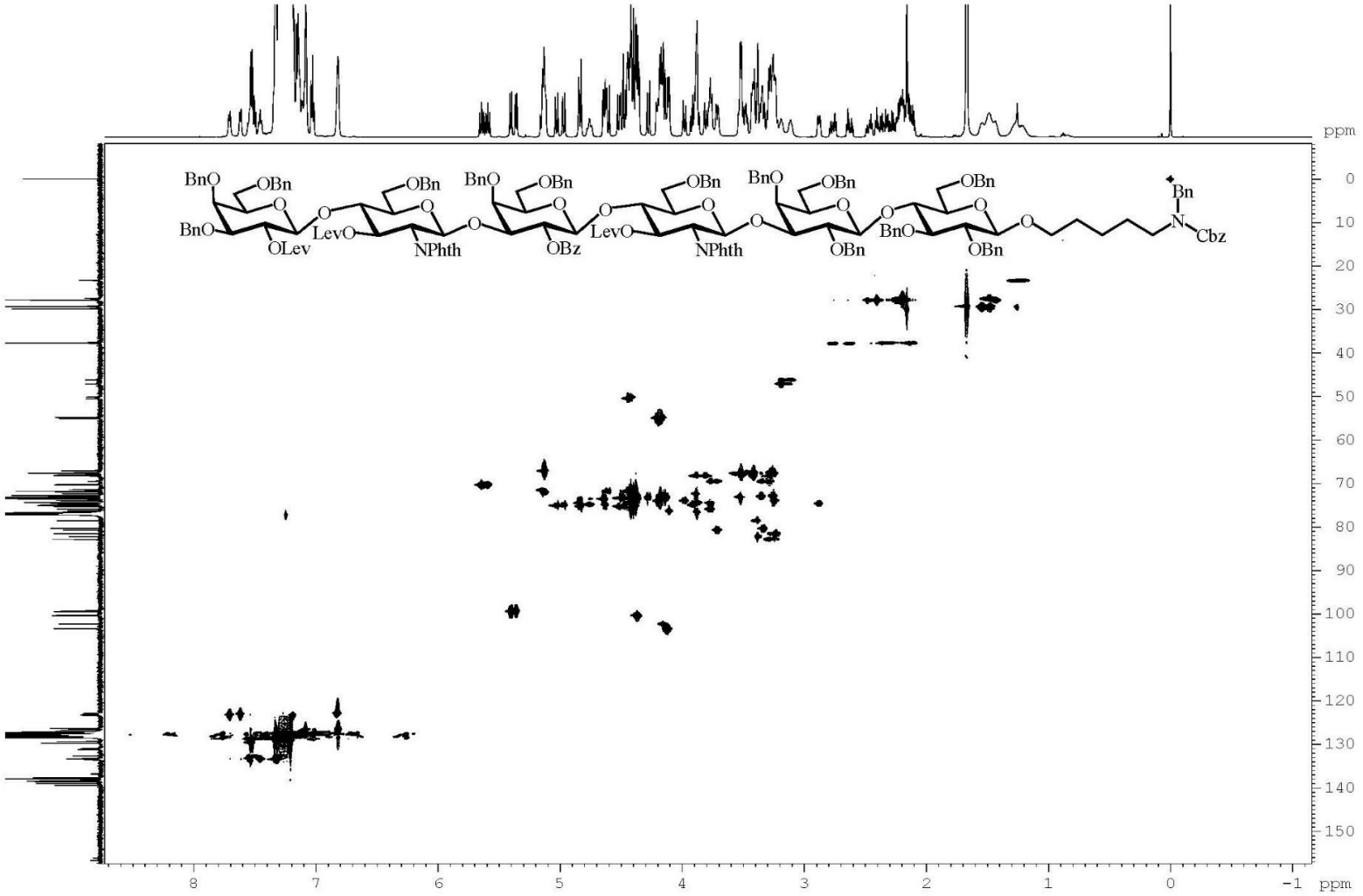
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 3



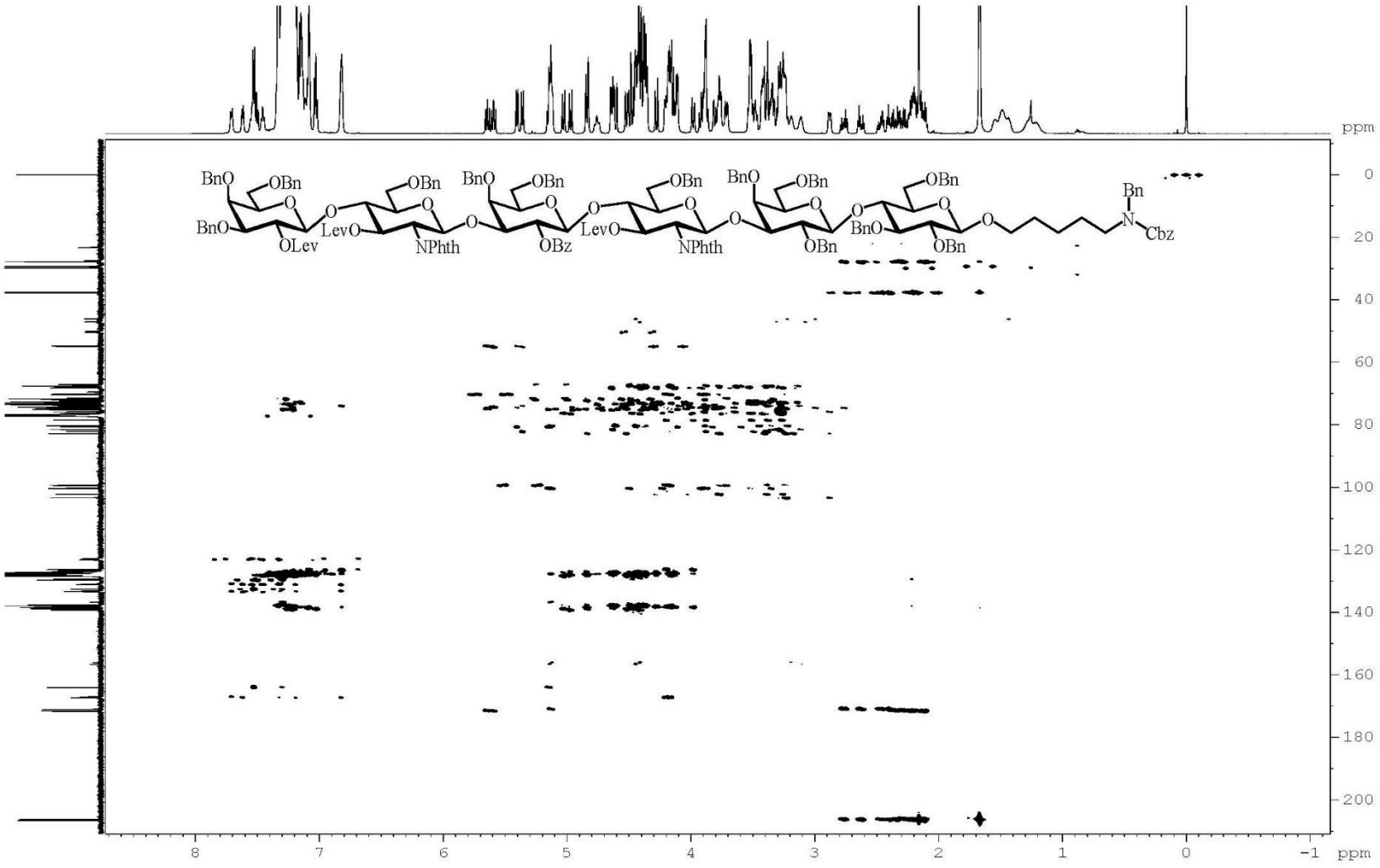
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 3



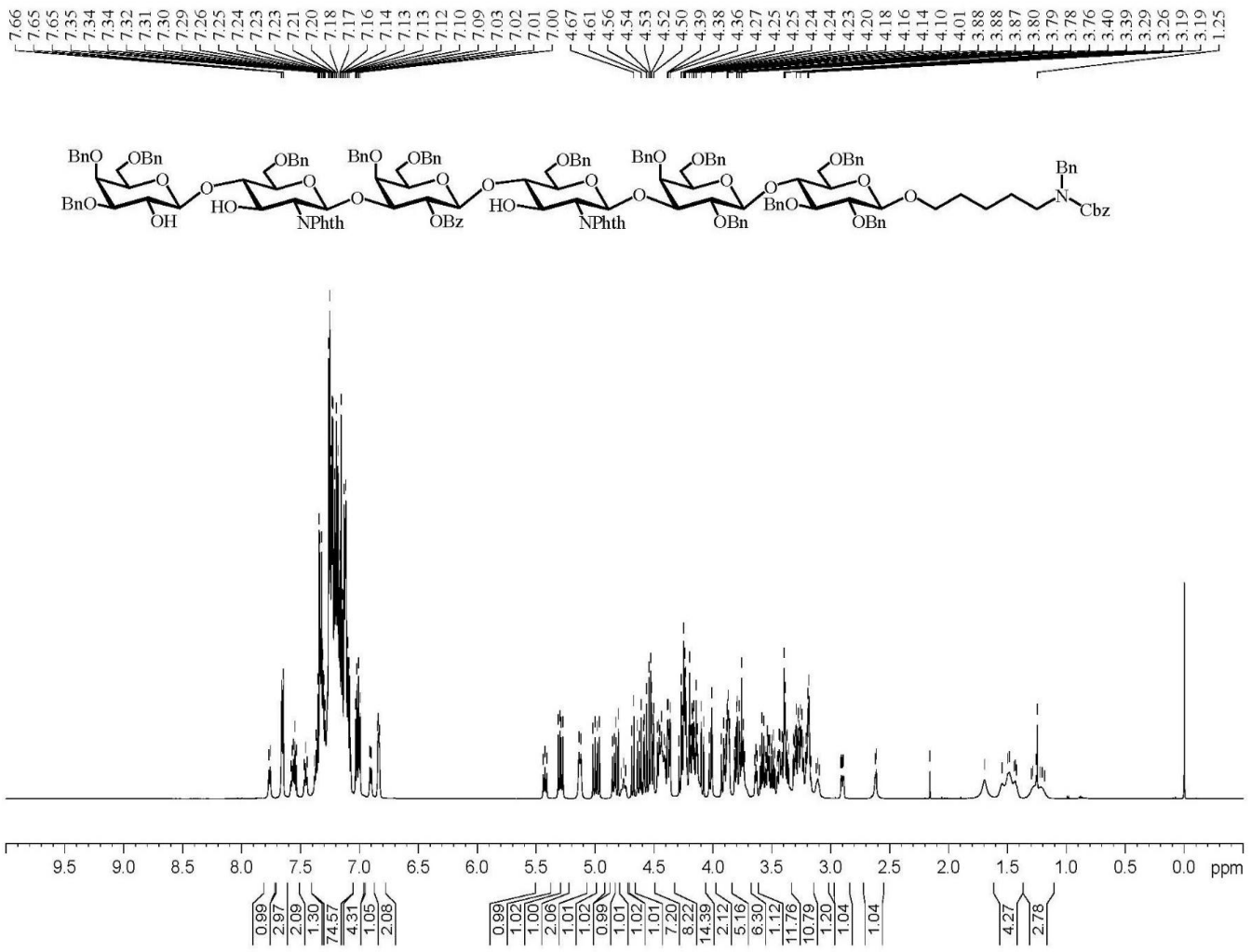
H-HCOSY spectrum of compound 3



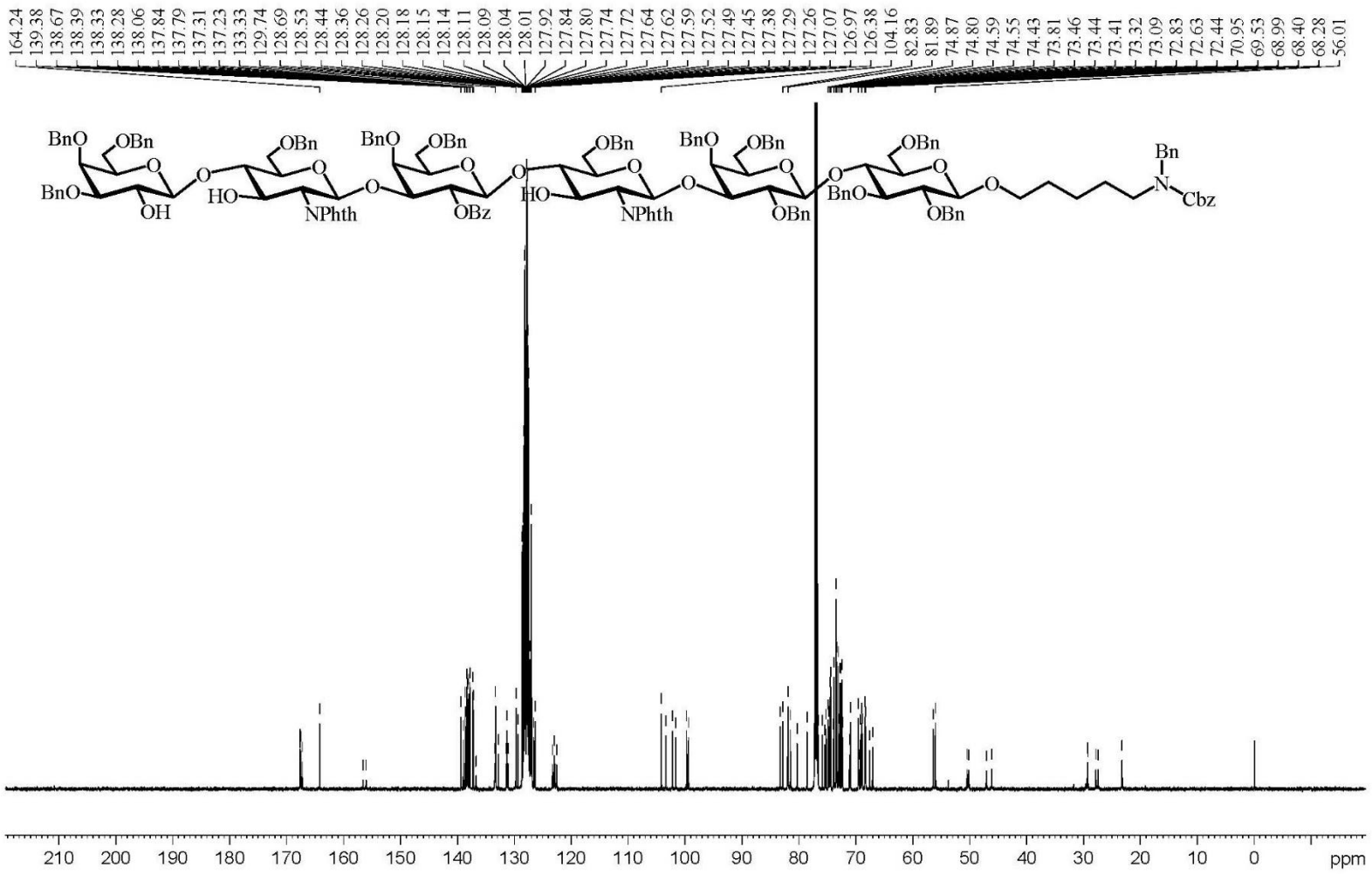
HSQC spectrum of compound 3



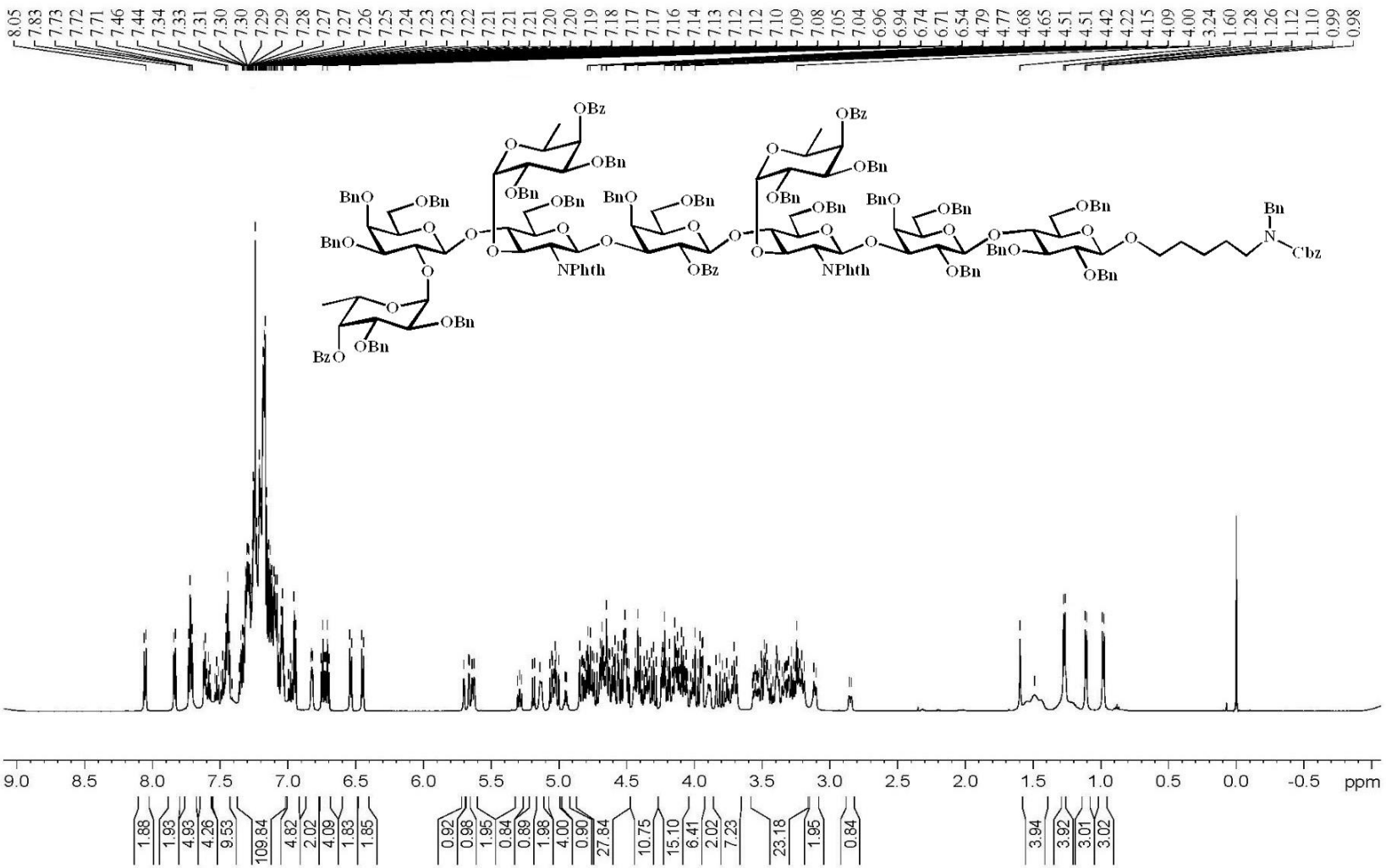
HMBC spectrum of compound 3



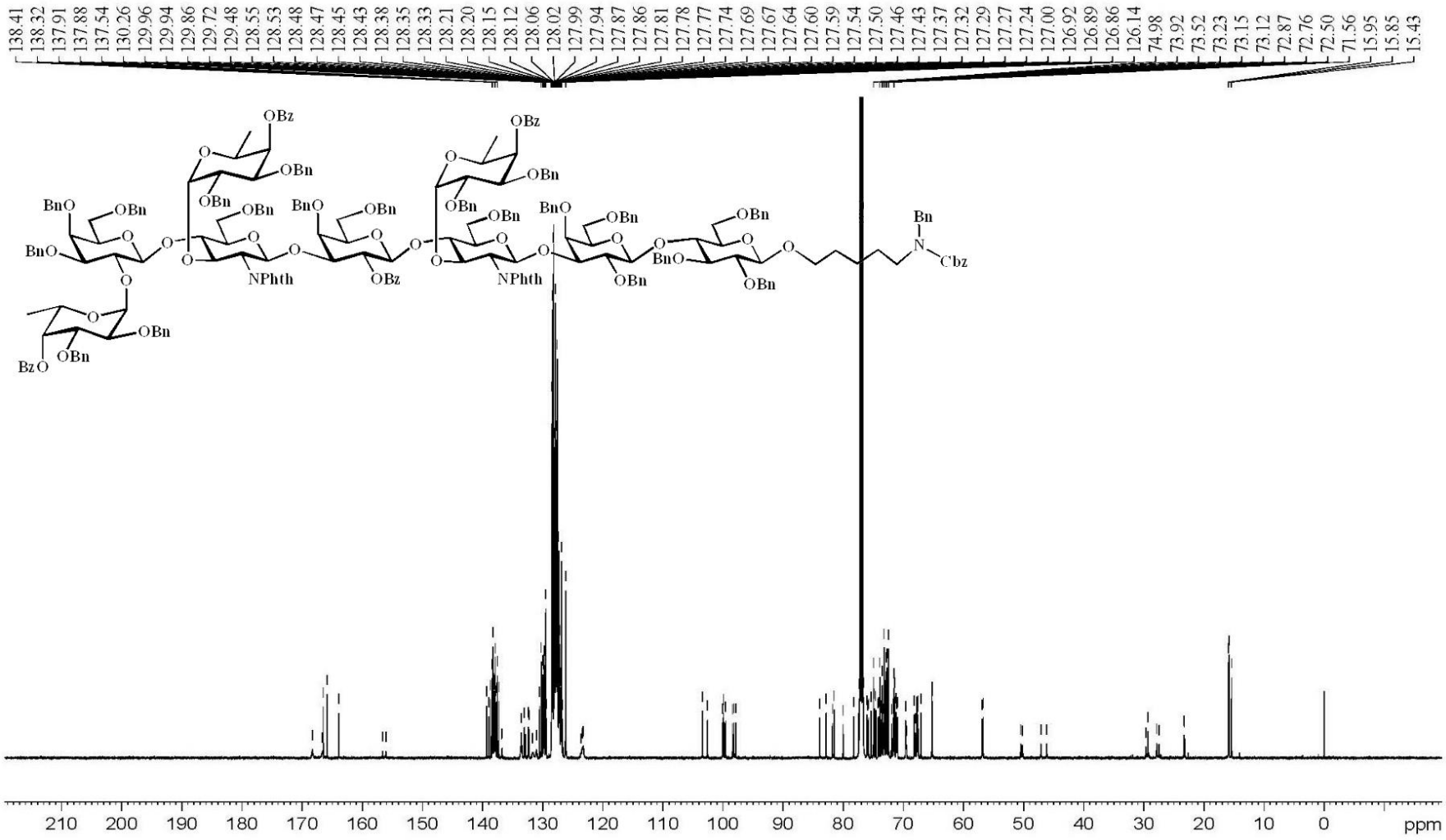
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 16



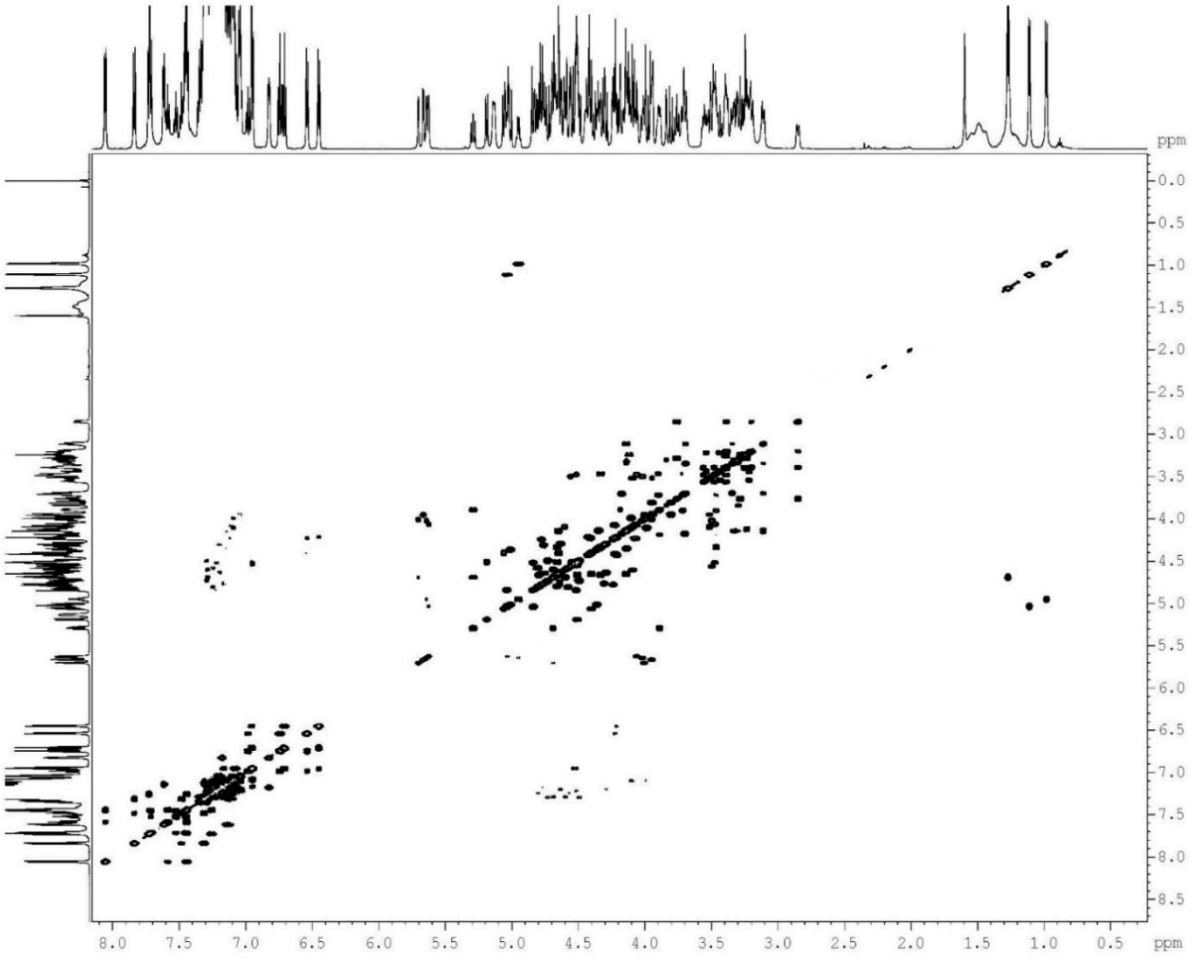
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 16



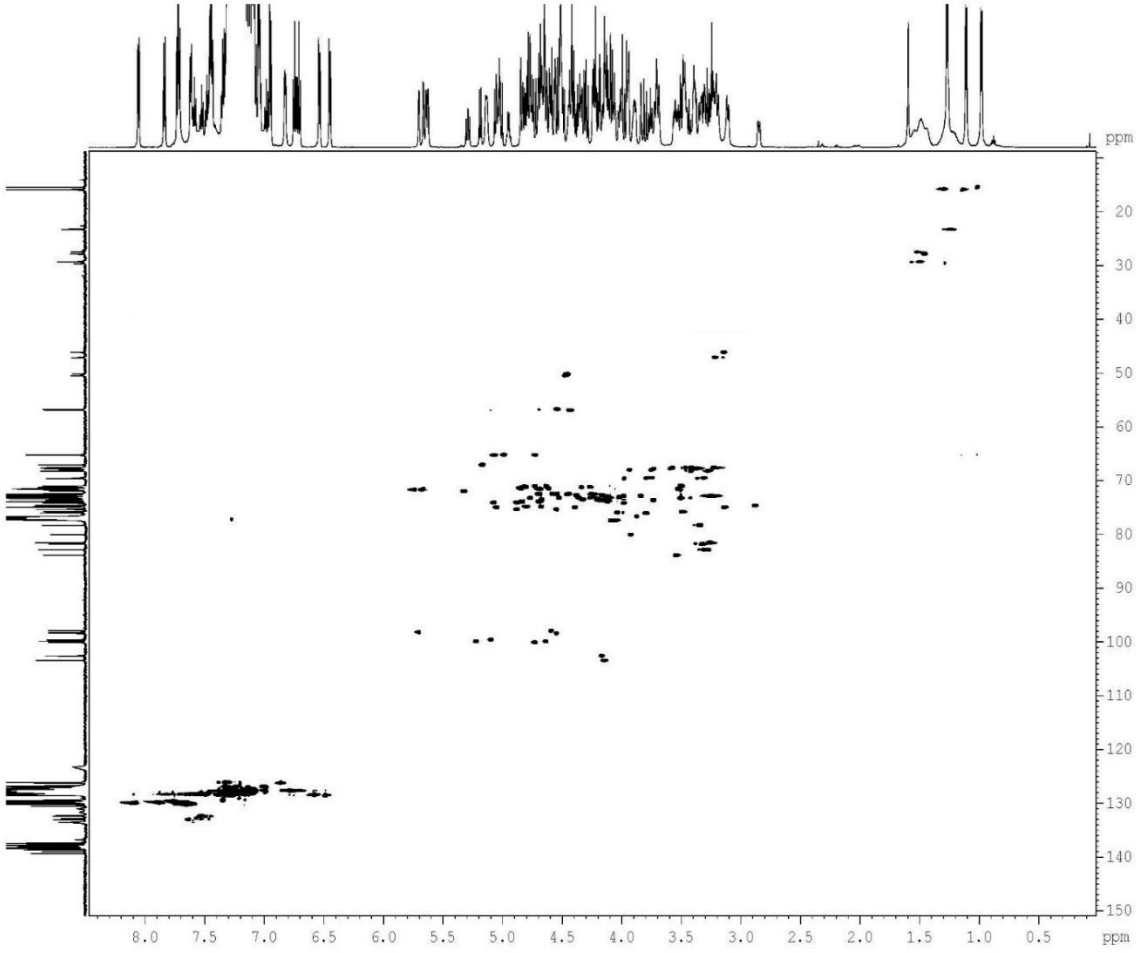
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound 2



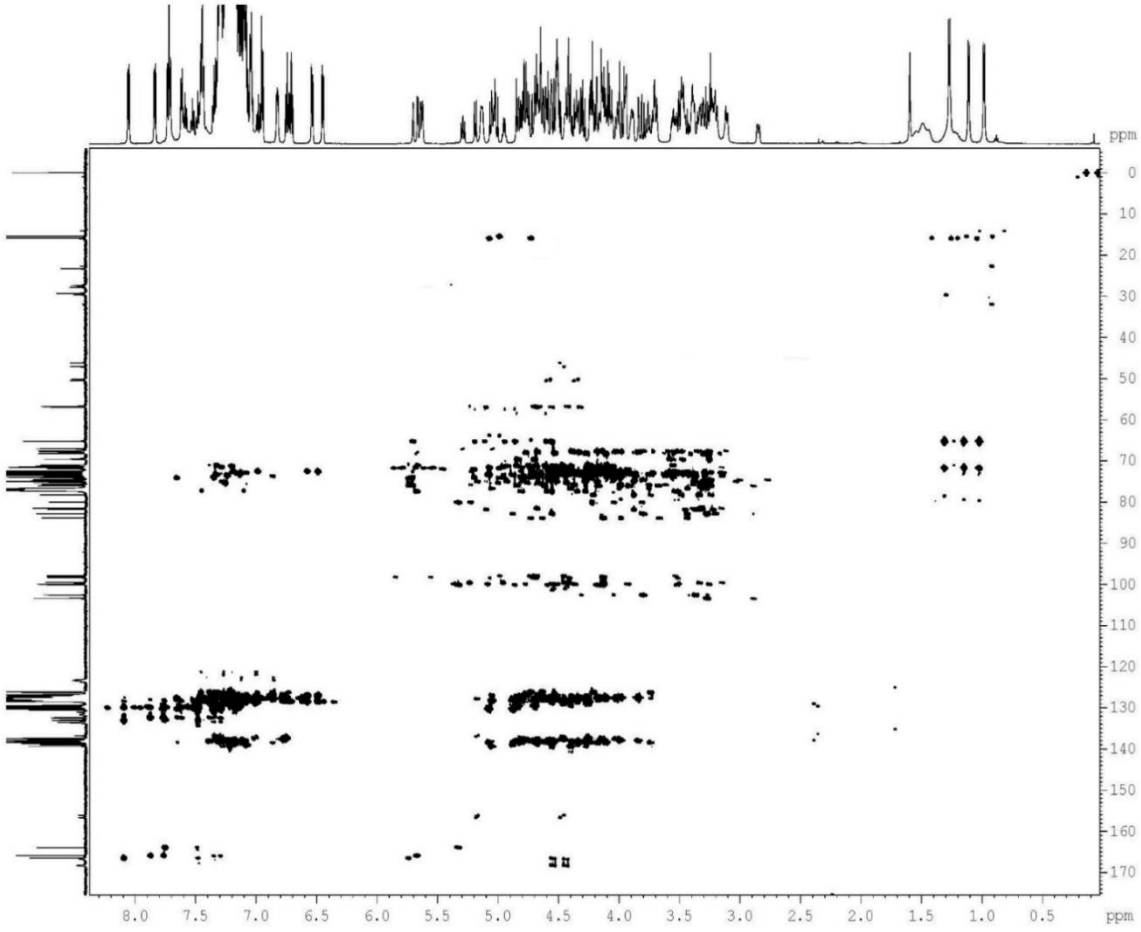
^{13}C NMR (151 MHz, $CDCl_3$) spectrum of compound 2



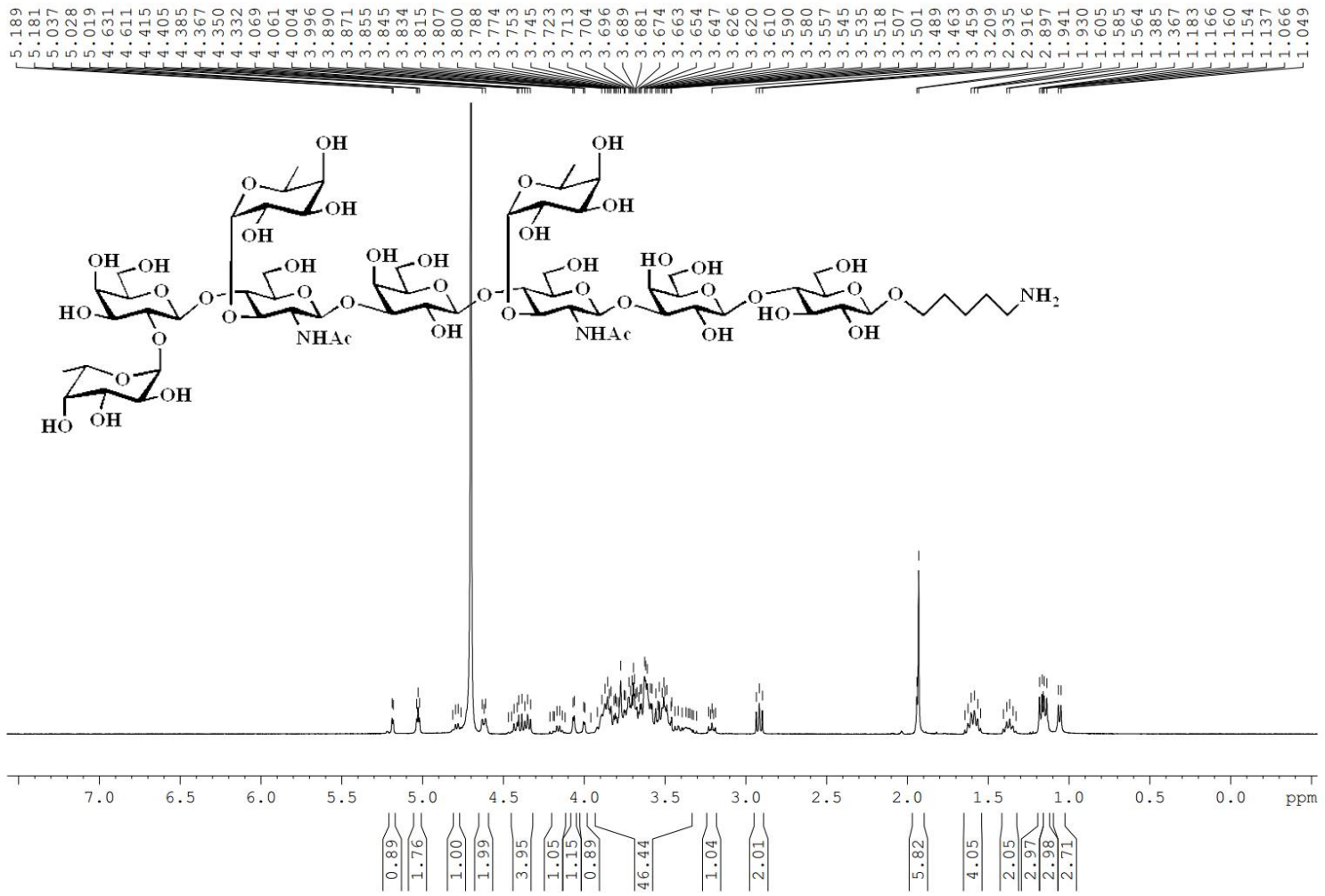
H-HCOSY spectrum of compound 2



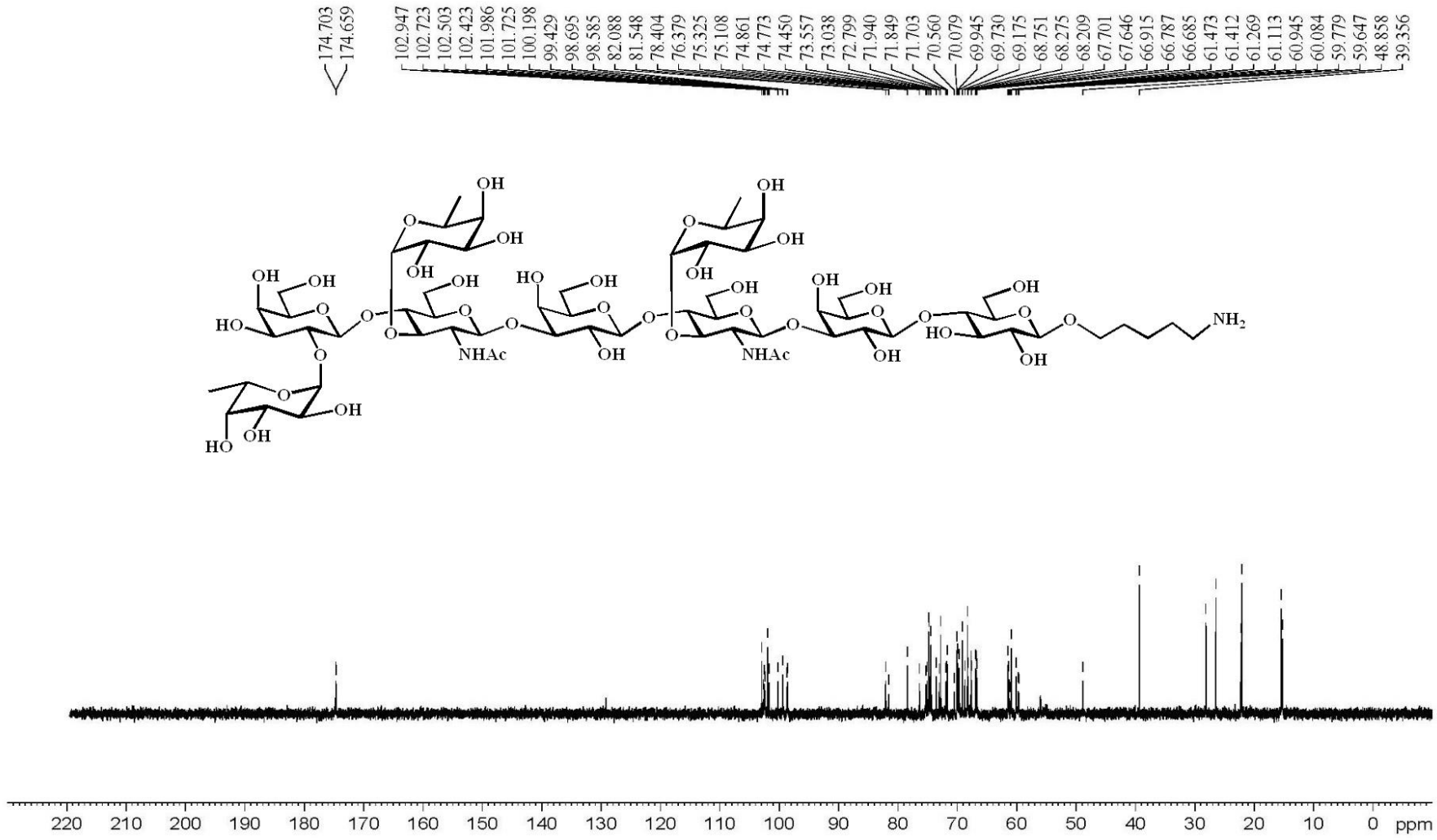
HSQC spectrum of compound 2



HMBC spectrum of compound 2



^{1}H NMR (400 MHz, D_2O) spectrum of compound 1



^{13}C NMR (151 MHz, D_2O) spectrum of compound 1