Supporting Information

# Matching Glycosyl Donor Reactivity to Sulfonate Leaving Group Ability Permits $S_N2$ Glycosylations

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# Supporting Information

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## 1. General Experiment Details

Unless otherwise described, all reactions were performed in standard, flame-dried glassware equipped with PTFE-coated magnetic stir bars and fit with rubber septa under an inert atmosphere of argon. Flash column chromatography was performed on SiliCycle P-60 silica gel, 230–400 Mesh. Analytical and preparative thin layer chromatography (TLC) was carried out on EMD silica gel 60 F-254 plates. Products were visualized using UV or by staining with 5% aqueous sulfuric acid. NMR spectra were recorded on a Bruker Avance III NMR spectrometer at 500 MHz for $^{1}$H NMR, 125 MHz for $^{13}$C NMR, and 500 MHz for Gradient HSQC and COSY. Chemical shifts are reported in ppm relative to tetramethylsilane (0.00 ppm for $^{1}$H NMR in $CDCl_3$) or $CDCl_3$ (77.16 ppm for $^{13}$C NMR in $CDCl_3$). For $^{1}$H NMR spectra, data are reported as follows: δ shift, multiplicity [s = singlet, d = doublet, dd = doublet of doublets, m = multiplet, t = triplet, td = triplet of doublets], coupling constants are reported in hertz (Hz). High-resolution mass spectra (HRMS) were obtained on Electro Spray Ionization (ESI) on a Waters Q-tof Premier instrument in the positive mode. Temperature was controlled by using Neslab CC100 immersion cooler. Optical rotations were measured on a Rudolph Research Analysis AUTOPUL IV polarimeter at 589 nm in a 5 cm at 23 $^{o}$C.

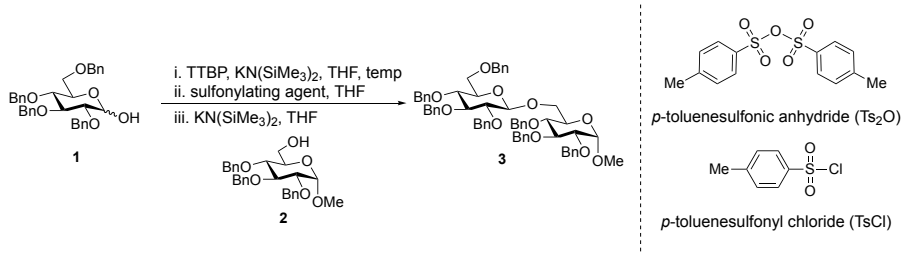
## 2. Materials

Prior to running the glycosylation reactions, all donors and acceptors were dried three times by azeotropic removal of water using toluene and a rotary evaporator and set under vacuum for 16 hrs before use. *p*-Nitrobenzenesulfonyl chloride **4h** is purified before use. **4h** is dissolved in diethyl ether and washed with aqueous 10% NaOH x 3 and brine x 1, then dried ($Na_2SO_4$) and crystalized by cooling in dry-ice bath under argon. **4h** is further dried over $P_2O_5$ in vacuum desiccator overnight. Solvents for reactions were dried on an Innovative Technologies PureSolv 400 solvent purifier. NMR solvents were purchased from Cambridge Isotope Laboratories. Glycosyl donors **1**[1], **10**[1], **29**[1], **36**[1], **6**[2], **7**[2], **8**[2], and **30**[3] and acceptors **2**[4], **11**[5], **12**[6], **13**[6], **14**[6b, 7], **15**[6], **16**[8] and **39**[9]were synthesized following literature procedures or variations thereof. All other chemicals were purchased at the highest possible purity from Carbosynth and Sigma-Aldrich and used as received. The 5 mm Low Pressure/Vacuum Valve NMR tube used for low-temperature NMR experiments was purchased from Wilmad LabGlass. Molecular sieves were activated by flame drying under vacuum three times, cooled to room temperature, and directly used for glycosylations.

# 3. Additional Optimization Data

## 3.1 Optimization for glycosylation of donor 1 with primary acceptor 2

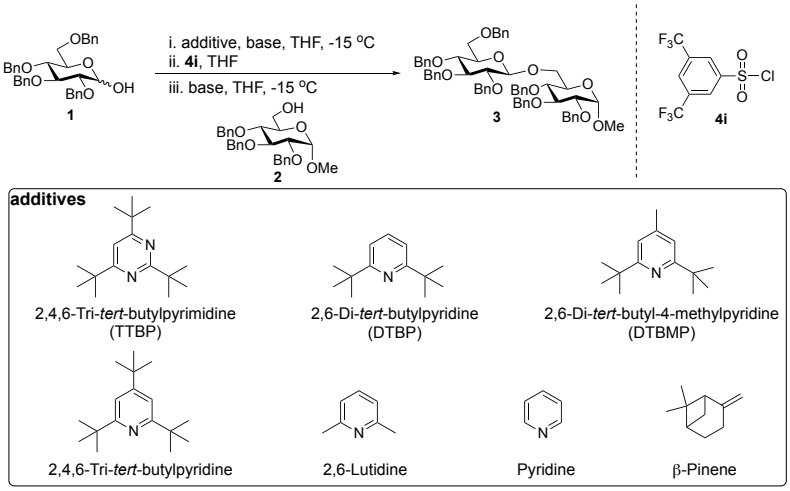
**Table S1.** Temperature and activation time optimization




| Entry[a] | Sulfonylating agent | Temp [°C] | Activation time [h] | Yield [%] (β only) |
|---|---|---|---|---|
| 1 | $Ts_2O$ | -78 | 0.5 | 5 |
| 2 | TsCl | -78 | 0.5 | 6 |
| 3 | TsCl | -35 | 0.5 | 8 |
| 4 | TsCl | -15 | 0.5 | 25 |
| 5 | TsCl | 0 | 0.5 | 25 |
| 6 | TsCl | 25 | 0.5 | 7 |
| 7 | TsCl | -15 | 1 | 25 |
| 8 | TsCl | -15 | 1.5 | 25 |
| **9** | **TsCl** | **-15** | **2** | **27** |

[a] 0.20 mmol of glucosyl donor **1**, 0.133 mmol of acceptor **2**, 0.2 mmol of sulfonylating agent, THF as solvent. Activation [**1**] = 0.080 M, glycosylation [**1**] = 0.050 M. Isolated yield. All selectivities based on $^1$H NMR analysis of purified material.

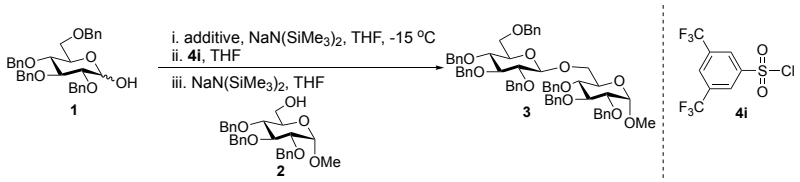
**Table S2.** Base and additives optimization




| Entry[a] | Base | Additive [mmol] | Yield [%] (β only) |
|---|---|---|---|
| 1 | $KN(SiMe_3)_2$ | None | 24 |
| 2 | $KN(SiMe_3)_2$ | TTBP (0.2) | 46 |
| 3 | $KN(SiMe_3)_2$ | DTBP (0.2) | 53 |
| 4 | $KN(SiMe_3)_2$ | DTBMP (0.2) | 51 |
| 5 | $KN(SiMe_3)_2$ | β-Pinene (0.2) | 51 |
| 6 | $LiN(SiMe_3)_2$ | DTBP (0.2) | NR |
| 7 | $NaN(SiMe_3)_2$ | DTBP (0.2) | 74 |
| 8 | $NaN(SiMe_3)_2$ | TTBP (0.2) | 69 |
| 9 | $NaN(SiMe_3)_2$ | DTBMP (0.2) | 69 |
| 10 | $NaN(SiMe_3)_2$ | 2,6-Lutidine (0.2) | 66 |
| 11 | $NaN(SiMe_3)_2$ | Pyridine (0.2) | NR |
| 12 | $NaN(SiMe_3)_2$ | 2,4,6-Tri-*tert*-butylpyridine (0.2) | 76 |
| 13 | $NaN(SiMe_3)_2$ | 2,4,6-Tri-*tert*-butylpyridine (0.1) | 80 |
| 14 | $NaN(SiMe_3)_2$ | 2,4,6-Tri-*tert*-butylpyridine (0.4) | 75 |
| 15 | $NaN(SiMe_3)_2$ | 2,4,6-Tri-*tert*-butylpyridine (0.8) | 69 |
| **16** | **$NaN(SiMe_3)_2$** | **None** | **81** |

[a] 0.20 mmol of glucosyl donor **1**, 0.133 mmol of acceptor **2**, 0.2 mmol of sulfonylating agent **4i**, THF as solvent, activation time 2 hrs, Activation [**1**] = 0.080 M, glycosylation [**1**] = 0.050 M. Isolated yield. NR = No Reaction. All selectivities based on $^1$H NMR analysis of purified material.

**Table S3.** Solvent and additives optimization

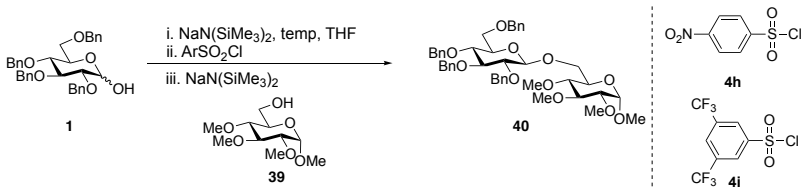



| Entry[a] | Solvent | Additive | Yield [%] (β only) |
|---|---|---|---|
| 1 | THF | 2,4,6-Tri-*tert*-butylpyridine (0.1 mmol) | 80 |
| 2 | glyme | 2,4,6-Tri-*tert*-butylpyridine (0.1 mmol) | 40 |
| 3 | diglyme | 2,4,6-Tri-*tert*-butylpyridine (0.1 mmol) | 20 |
| 4 | $Et_2O$ | 2,4,6-Tri-*tert*-butylpyridine (0.1 mmol) | 52 |
| 5 | $CH_2Cl_2$ | 2,4,6-Tri-*tert*-butylpyridine (0.1 mmol) | 60 |
| **6** | **THF** | **None** | **81** |
| 7 | toluene | None | 60 |
| 8 | MeCN | None | NR |
| 9 | THF/toluene = 4/1 | None | 63 |
| 10 | THF/$CH_2Cl_2$ = 4/1 | None | 51 |
| 11 | THF/1,4-dioxane = 3/1 | None | 52 |
| 12 | THF | 15-Crown-5 (0.2 mmol) | 41 |
| 13 | THF | activated 4 Å MS (200 mg) | 68 |
| 14 | THF | activated 5 Å MS (200 mg) | 68 |

[a] 0.20 mmol of glucosyl donor **1**, 0.133 mmol of acceptor **2**, 0.2 mmol of sulfonylating agent **4i**, activation time 2 hrs, activation [**1**] = 0.080 M, glycosylation [**1**] = 0.050 M. Isolated yield. NR = No Reaction, MS = Molecular Sieves. All selectivities based on $^1$H NMR analysis of purified material.

## 3.2 Optimization for glycosylation of donor 1 with primary acceptor 39 for kinetic isotope effect study

**Table S4.** Stoichiometry, temperature and reaction time optimization

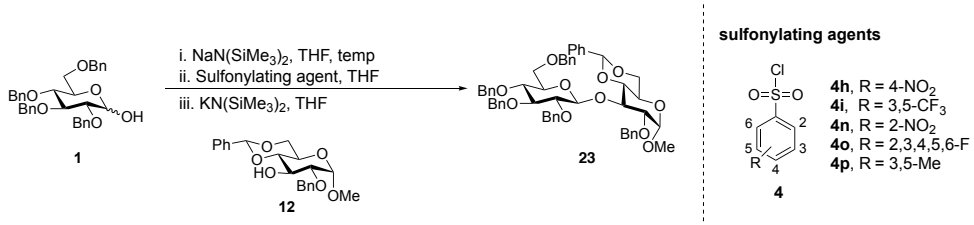



| Entry[a] | Sulfonylating agent | Temp [°C] | Reaction time | Yield [%] (β only) |
|---|---|---|---|---|
| 1[b] | **4h** | -30 | 3 h | 90 |
| 2[b] | **4i** | -30 | 3 h | 91 |
| 3 | **4i** | -30 | 5 min | 80 |
| 4 | **4i** | -30 | 10 min | 80 |
| 5 | **4i** | -30 | 6 h | 82 |
| 6 | **4i** | -30 | 12 h | 82 |
| 7 | **4h** | -30 | 12 h | 70 |
| 8 | **4i** | -60 | 10 min | 36 |
| 9 | **4i** | -60 | 20 min | 56 |
| **10** | **4i** | **-60** | **6 h** | **91** |

[a] 0.20 mmol of glucosyl donor **1**, 0.2 mmol of sulfonylating agent, 0.40 mmol of acceptor **39**, activation time 2 hrs, activation [**1**] = 0.091 M, glycosylation [**1**] = 0.036 M. Isolated yield. [b] All selectivities based on $^1$H NMR analysis of purified material. [b] 0.20 mmol of glucosyl donor **1**, 0.20 mmol of sulfonylating agent, 0.1 mmol of acceptor **39**. Activation [**1**] = 0.080 M, glycosylation [**1**] = 0.057 M.

### 3.3 Optimization for glycosylation of donor 1 with secondary acceptor 12

**Table S5.** Sulfonylating agent, stoichiometry, temperature and concentration optimization




| Entry[a] | Sulfonylating agent | Temp [°C] | Glycosylation [**1**] | Equiv. (**1**:**12**) | Yield [%] (β:α) |
|---|---|---|---|---|---|
| 1 | **4h** | -20 | 0.057 M | 2:1 | 55% (5:1) |
| 2 | **4i** | -20 | 0.057 M | 2:1 | 73% (4:1) |
| 3 | **4o** | -20 | 0.057 M | 2:1 | 11% (2:1) |
| 4 | **4p** | -20 | 0.057 M | 2:1 | Trace |
| 5 | **4n** | -30 | 0.080 M | 2:1 | 47% (8:1) |
| 6 | **4h** | -30 | 0.050 M | 2:1 | 49% (10:1) |
| 7 | **4h** | -30 | 0.060 M | 2:1 | 49% (8:1) |
| 8 | **4h** | -30 | 0.070 M | 2:1 | 53% (6:1) |
| 9 | **4h** | -30 | 0.057 M | 3:1 | 59% (14:1) |
| 10[b] | **4h** | -30 | 0.057 M | 3:1 | 60% (14:1) |
| 11 | **4i** | -40 | 0.057 M | 3:1 | 56% (14:1) |
| 12[b] | **4i** | -40 | 0.057 M | 3:1 | 58% (14:1) |

[a] 0.20 mmol of glucosyl donor **1**, 0.20 mmol of sulfonylating agent, activation time 2 hrs, Activation [**1**] = 0.080 M. Isolated yield. All selectivities based on $^1$H NMR analysis of purified material. [b] 0.60 mmol of glucosyl donor **1**, 0.60 mmol of sulfonylating agent, 0.20 mmol of acceptor **12**.

## 4. Experimental Data

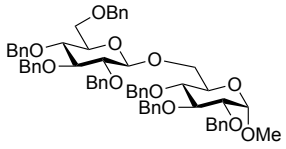
### 4.1 Procedures for glycosylation and experimental data

***General glycosylation procedure***: A solution of donor in THF was cooled to identical temperature and treated with sodium hexamethyldisilazane (1.0 M in THF). After 10 mindutes, this solution was transferred by syringe to a flask containing the solution of promoter sulfonyl chloride in THF that had been pre-cooled to the same temperature. The flask that contained the donor was then rinsed with an additional THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor in THF at the same temperature with sodium hexamethyldisilazane or potassium hexamethyldisilazane and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with THF, and this rinse was then added to the glycosylation reaction.

***Work-up procedure***: The reaction was quenched with saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether four times. The combined organic phase was washed with brine and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure.

***Yield and selectivity determination***: The crude reaction mixture was purified by silica gel flash column chromatography to afford β and α products. The selectivity was determined by $^1H$ NMR integration of the anomeric signals. If the β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**Methyl 2,3,4-*O*-tribenzyl-6-*O*-(2,3,4,6-*O*-tetrabenzyl-β-D-glucopyranosyl)-α-D-glucopyranoside 3**



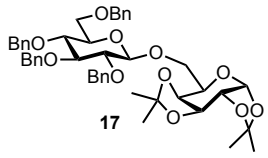

**3**

A solution of donor **1** (0.1080 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the

donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 3 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **3** as a single β-isomer (0.0836 g, 0.085 mmol, 85% yield) when **4h** was used as the promoter or (0.0947 g, 0.096 mmol, 96% yield) when **4i** was used as the promoter.

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.35 – 7.11 (m, 35H), 4.98 (d, *J* = 4.0 Hz, 1H), 4.95 (d, *J* = 3.9 Hz, 1H), 4.90 (d, *J* = 10.9 Hz, 1H), 4.83 – 4.69 (m, 6H), 4.65 (d, *J* = 12.1 Hz, 1H), 4.60 (d, *J* = 3.1 Hz, 1H), 4.58 – 4.49 (m, 4H), 4.34 (d, *J* = 7.8 Hz, 1H), 4.18 (dd, *J* = 10.8, 1.8 Hz, 1H), 3.99 (t, *J* = 9.3 Hz, 1H), 3.84 – 3.81 (m, 1H), 3.70 – 3.63 (m, 3H), 3.61 (d, *J* = 9.0 Hz, 1H), 3.56 (t, *J* = 9.3 Hz, 1H), 3.53 – 3.45 (m, 3H), 3.45 – 3.40 (m, 1H), 3.32 (s, 3H).
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.7, 138.5, 138.5, 138.4, 138.3, 138.3, 128.6, 128.5, 128.5, 128.5, 128.3, 128.1, 128.1, 128.0, 128.0, 127.9, 127.8, 127.7, 127.7, 127.7, 127.6, 104.0, 98.2, 84.9, 82.2, 82.1, 79.9, 78.2, 78.1, 75.8, 75.8, 75.2, 75.1, 75.0, 73.6, 73.5, 70.0, 69.2, 68.7, 55.3. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[10]

**6-*O*-(2,3,4,6-*O*-tetrabenzyl-β-D-galactopyranosyl)-1,2;3,4-*O*-diisopropylidene-α-D-galactopyranoside 17**




A solution of donor **1** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the

donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **11** (0.0347 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -30 °C with sodium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 4 hours, the reaction was quenched with 0.1 mL of saturated, aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **17** (0.0739 g, 0.094 mmol, 71% yield, β:α 17:1) when **4h** was used as the promoter or (0.0957 g, 0.122 mmol, 92% yield, β:α 10:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **17**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.45 – 7.07 (m, 20H), 5.57 (d, *J* = 5.0 Hz, 1H), 5.06 (d, *J* = 11.1 Hz, 1H), 4.96 (d, *J* = 10.9 Hz, 1H), 4.82 – 4.76 (m, 2H), 4.72 (d, *J* = 11.1 Hz, 1H), 4.64 – 4.56 (m, 2H), 4.55 – 4.47 (m, 2H), 4.46 (d, *J* = 7.8 Hz, 1H), 4.31 (dd, *J* = 5.0, 2.4 Hz, 1H), 4.24 (dd, *J* = 7.9, 1.7 Hz, 1H), 4.16 (dd, *J* = 10.7, 3.6 Hz, 1H), 4.11 – 4.06 (m, 1H), 3.75 – 3.67 (m, 3H), 3.66 – 3.58 (m, 2H), 3.50 – 3.39 (m, 2H), 1.50 (s, 3H), 1.45 (s, 3H), 1.31 (d, *J* = 2.7 Hz, 6H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 138.8, 138.2, 128.7, 128.4, 128.4, 128.3, 128.0, 127.9, 127.9, 127.7, 127.6, 127.6, 127.5, 109.4, 108.6, 104.4, 96.4, 84.6, 81.7, 77.8, 75.7, 75.0, 74.8, 74.4, 73.5, 71.5, 70.8, 70.5, 69.8, 68.8, 67.4, 26.1, 26.0, 25.1, 24.5. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[11]

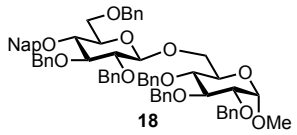
**α-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.41 – 7.05 (m, 20H), 5.52 (d, *J* = 5.0 Hz, 1H), 5.00 – 4.97 (m, 2H), 4.81 (t, *J* = 10.6 Hz, 2H), 4.75 (d, *J* = 11.9 Hz, 1H), 4.69 (d, *J* = 11.9 Hz, 1H), 4.64 – 4.57 (m, 2H), 4.48 (d, *J* = 4.3 Hz, 1H), 4.46 (d, *J* = 5.7 Hz, 1H), 4.35 (dd, *J* = 8.0, 1.7 Hz, 1H), 4.31 (dd, *J* = 5.0, 2.3 Hz, 1H), 4.04 (t, *J* = 6.9 Hz, 1H), 3.98 (t, *J* = 9.3 Hz, 1H), 3.85 – 3.71 (m, 4H), 3.71 – 3.62 (m, 2H), 3.58 (dd, *J* = 9.6, 3.6 Hz, 1H), 1.53 (s, 3H), 1.45 (s, 3H), 1.32 (d, *J* = 6.8 Hz, 6H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.1, 138.5, 138.5, 138.2, 128.5, 128.1, 128.0, 128.0, 127.8, 127.8, 127.7, 109.4, 108.7, 97.2, 96.5, 82.1, 80.0, 77.8, 77.4, 77.2, 76.9, 75.8,

75.1, 73.6, 72.5, 71.0, 70.9, 70.8, 70.4, 68.6, 66.4, 65.9, 26.3, 26.2, 25.1, 24.8. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[12]

**Methyl 6-*O*-(4-*O*-(2-naphthylmethyl)-2,3,6-tri-*O*-benzyl-β-D-glucopyranosyl)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 18**



**18**

A solution of donor **5** (0.1180 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mLof THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 3 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (17% ethyl acetate in hexane) to afford disaccharide **18** as a single β-isomer (0.0556 g, 0.054 mmol, 54% yield) when **4h** was used as the promoter or (0.0713 g, 0.069 mmol, 69% yield) when **4i** was used as the promoter.

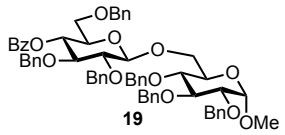
**$[\alpha]_D^{22}$** = +21.8° (*c* 1.2, $CH_2Cl_2$);
**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.84 – 7.68 (m, 3H), 7.59 (s, 1H), 7.47 – 7.45 (m, 2H), 7.39 – 7.12 (m, 31H), 4.99 – 4.91 (m, 4H), 4.85 – 4.56 (m, 9H), 4.56 – 4.43 (m, 2H), 4.36 (d, *J* = 7.8 Hz, 1H), 4.18 (d, *J* = 9.7 Hz, 1H), 3.99 (t, *J* = 9.2 Hz, 1H), 3.88 – 3.79 (m, 1H), 3.79 – 3.56 (m, 5H), 3.56 – 3.40 (m, 4H), 3.32 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 138.9, 138.6, 138.4, 138.4, 138.3, 138.2, 135.6, 133.3, 133.0, 128.5, 128.4, 128.4, 128.3, 128.1, 128.1, 128.0, 127.9, 127.9, 127.9, 127.7, 127.6,

127.6, 127.6, 127.5, 127.5, 126.6, 126.1, 126.0, 125.9, 103.9, 98.1, 84.9, 82.1, 82.0, 79.8, 78.1, 78.0, 75.7, 75.7, 75.1, 75.0, 74.9, 73.5, 73.4, 69.9, 69.1, 68.6, 55.2.

**LRMS (ESI) m/z**: calculated for $C_{66}H_{68}NaO_{11}$ (M+Na) = 1059.46; found 1059.62;
**HRMS (ESI) m/z**: calculated for $C_{66}H_{68}NaO_{11}$ (M+Na) = 1059.4659; found 1059.4613.

**Methyl 6-*O*-(4-*O*-Benzoyl-2,3,6-tri-*O*-benzyl-β-D-glucopyranosyl)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 19**



**19**

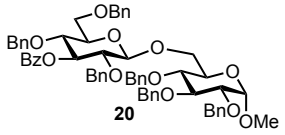
A solution of donor **6** (0.1108 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mLof THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 5 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **19** as a single β-isomer (0.0821 g, 0.082 mmol, 82% yield) when **4h** was used as the promoter or (0.0889 g, 0.089 mmol, 90% yield) when **4i** was used as the promoter.

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.98 – 7.85 (m, 2H), 7.56 (dd, *J* = 10.6, 4.3 Hz, 1H), 7.41 (t, *J* = 7.8 Hz, 2H), 7.37 – 7.22 (m, 16H), 7.22 – 7.09 (m, 11H), 7.12 – 6.97 (m, 5H), 5.21 (t, *J* = 9.6 Hz, 1H), 4.97 (d, *J* = 10.9 Hz, 2H), 4.81 – 4.69 (m, 5H), 4.68 – 4.57 (m, 3H), 4.52 (d, *J* = 11.2 Hz, 1H), 4.45 (dd, *J* = 7.8, 4.9 Hz, 3H), 4.20 (dd, *J* =

1.9, 1.8 Hz, 1H), 4.00 (t, *J* = 9.3 Hz, 1H), 3.87 – 3.81 (m, 1H), 3.75– 3.71 (m, 2H), 3.70 – 3.62 (m, 1H), 3.62 – 3.58 (m, 3H), 3.57 – 3.49 (m, 2H), 3.34 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 165.4, 138.9, 138.4, 138.3, 138.2, 137.9, 133.2, 129.8, 129.7, 128.5, 128,4, 128.4, 128.3, 128.2, 128.1, 128.0, 127.9, 127.9, 127.9, 127.6, 127.6, 127.6, 127.5, 127.5, 127.5, 103.7, 98.1, 82.0, 81.9, 81.7, 79.9, 78.0, 75.7, 75.1, 75.0, 74.9, 73.8, 73.6, 73.4, 71.6, 69.9, 69.8, 68.6, 55.2. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[2, 13]

**Methyl 6-*O*-(3-*O*-benzoyl-2,3,6-tri-*O*-benzyl-β-D-glucopyranosyl)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 20**



**20**

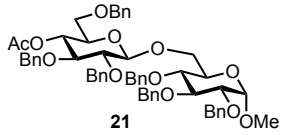
A solution of donor **7** (0.1108 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 5 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (18% ethyl acetate in hexane) to afford disaccharide **20** as a single β-isomer (0.0329 g, 0.033 mmol, 33% yield) when **4h** was used as the promoter or (0.0652 g, 0.065 mmol, 65% yield) when **4i** was used as the promoter.

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.93 (d, *J* = 7.3 Hz, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.44 – 6.90 (m, 32H), 5.48 (t, *J* = 9.4 Hz, 1H), 4.98 (d, *J* = 10.9 Hz, 1H), 4.85 – 4.72 (m, 4H), 4.69 – 4.56 (m, 5H), 4.54 – 4.52 (m, 2H), 4.49 – 4.38 (m, 3H), 4.18 (dd, *J* = 10.8,

1.5 Hz, 1H), 4.01 (t, *J* = 9.3 Hz, 1H), 3.84 (dd, *J* = 10.0, 3.2 Hz, 1H), 3.77 – 3.63 (m, 4H), 3.60 – 3.46 (m, 4H), 3.36 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 165.6, 138.8, 138.3, 138.2, 137.8, 137.5, 133.0, 130.1, 129.8, 128.5, 128.5, 128.4, 128.4, 128.3, 128.3, 128.2, 128.2, 128.1, 128.1, 128.0, 128.0, 127.8, 127.8, 127.7, 127.7, 127.7, 127.6, 127.5, 103.8, 98.1, 82.0, 79.9, 78.9, 78.1, 76.5, 76.1, 75.8, 75.0, 74.9, 74.5, 74.3, 73.6, 73.4, 70.1, 68.7, 68.6, 55.3. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[2]

**Methyl 6-*O*-(4-*O*-acetyl-2,3,6-tri-*O*-benzyl-β-D-glucopyranosyl)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 21**



**21**

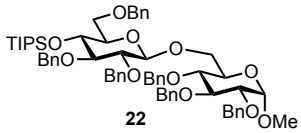
A solution of donor **8** (0.0984 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 5 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (20% ethyl acetate in hexane) to afford disaccharide **21** as a single β-isomer (0.0675 g, 0.072 mmol, 72% yield) when **4h** was used as the promoter or (0.0781 g, 0.083 mmol, 83% yield) when **4i** was used as the promoter.

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.50 – 7.01 (m, 30H), 4.99 – 4.89 (m, 3H), 4.84 – 4.75 (m, 3H), 4.73 – 4.71 (m, 2H), 4.69 – 4.55 (m, 3H), 4.52 – 7.01 (m, 3H), 4.37 (d, *J* = 7.6 Hz, 1H), 4.17 (dd, *J* = 10.7, 1.7 Hz, 1H), 3.99 (t, *J* = 9.3 Hz, 1H), 3.82 (dd, *J* = 10.0,

2.7 Hz, 1H), 3.69 (dd, *J* = 10.8, 4.6 Hz, 1H), 3.62 – 3.45 (m, 7H), 3.33 (s, 3H), 1.82 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 169.8, 138.9, 138.4, 138.4, 138.2, 138.2, 138.0, 128.5, 128.4, 128.2, 128.0, 127.9, 127.8, 127.8, 127.7, 127.6, 127.6, 127.6, 103.7, 98.1, 82.0, 81.9, 81.8, 79.9, 78.0, 75.7, 75.1, 75.0, 74.9, 73.6, 73.5, 73.4, 71.2, 70.0, 69.8, 68.7, 55.3, 20.8. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[2]

**Methyl 6-O-(4-*O*-triisopropylsilyl-2,3,6-tri-*O*-benzyl-β-D-glucopyranosyl)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 22**



**22**

A solution of donor **9** (0.1212 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 18 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (12% ethyl acetate in hexane) to afford disaccharide **22** as a single β-isomer (0.0550 g, 0.052 mmol, 52% yield) when **4h** was used as the promoter or (0.0602 g, 0.057 mmol, 57% yield) when **4i** was used as the promoter.

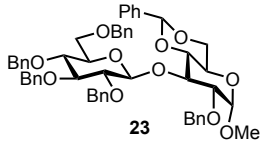
**$[\alpha]_D^{22}$** = +37.9° (*c* 2.0, $CH_2Cl_2$);

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.38 – 7.09 (m, 30H), 5.07 (d, *J* = 11.5 Hz, 1H), 4.98 – 4.94 (m, 2H), 4.81 – 4.73 (m, 2H), 4.70 (d, *J* = 11.1 Hz, 1H), 4.64 – 4.61 (m, 2H), 4.60 – 4.52 (m, 3H), 4.52 – 4.46 (m, 2H), 4.43 (d, *J* = 7.5 Hz, 1H), 4.20 (dd, *J* = 10.8, 1.8 Hz, 1H), 3.97 (t, *J* = 9.3 Hz, 1H), 3.82 (dd, *J* = 10.0, 2.8 Hz, 1H), 3.79 – 3.75 (m, 1H), 3.75 – 3.65 (m, 2H), 3.60 (dd, *J* = 10.5, 6.5 Hz, 1H), 3.53 – 3.39 (m, 5H), 3.30 (s, 3H), 0.96 – 0.90 (m, 21H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.1, 138.9, 138.4, 138.3, 138.2, 128.5, 128.4, 128.3, 128.3, 128.3, 128.1, 128.0, 128.0, 127.9, 127.7, 127.7, 127.7, 127.6, 127.5, 127.4, 127.0, 126.8, 103.4, 98.1, 84.8, 82.8, 82.0, 79.9, 78.1, 76.9, 75.7, 74.9, 74.2, 74.2, 73.5, 73.4, 71.5, 70.1, 69.9, 68.3, 55.2, 18.3, 18.1, 13.3.

**LRMS (ESI) m/z**: calculated for $C_{64}H_{80}NaO_{11}Si$ (M+Na) = 1075.54; found 1075.63; **HRMS (ESI) m/z**: calculated for $C_{64}H_{80}NaO_{11}Si$ (M+Na) = 1075.5368; found 1075.5378.

**Methyl 2-*O*-benzyl-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl)-(1→3)-4,6-*O*-benzylidene-α-D-glucopyranoside 23**



**23**

A solution of donor **1** (0.3242 g, 0.6 mmol, 3 equiv.) in 3.0 mL of THF was cooled to -30 °C or -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.6 mL, 0.6 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.1326 g, 0.6 mmol, 3 equiv., -30 °C) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1871 g, 0.6 mmol, 3 equiv., -40 °C) in 3.0 mL of THF that had been pre-cooled to corresponding temperature. The flask that contained the donor was then rinsed with an additional 1.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **12** (0.0744 g, 0.2 mmol, 1 equiv.) in 2.0 mL of THF at -30 °C or -40 °C with potassium hexamethyldisilazane (0.2 mL, 0.2 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 1.0 mL of THF, and this rinse was then added to the glycosylation reaction. After 18 hours, the reaction was quenched with 0.15 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 20 mL). The combined organic phase was washed with brine (40 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column

chromatography (15% ethyl acetate in hexane) to afford disaccharide **23** (0.1073 g, 0.12 mmol, 60% yield, β:α 14:1) when **4h** was used as the promoter or (0.1038 g, 0.12 mmol, 58% yield, β:α 14:1) when **4i** was used as the promoter. The selectivity was determined by $^{1}$H NMR integration of the anomeric signals of purified **23**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.44 – 7.13 (m, 30H), 5.47 (s, 1H), 5.06 (d, *J* = 11.2 Hz, 1H), 4.90 (dd, *J* = 11.5, 9.5 Hz, 2H), 4.81 – 4.68 (m, 4H), 4.53 (d, *J* = 10.7 Hz, 1H), 4.47 – 4.45 (m, 4H), 4.36 (t, *J* = 9.1 Hz, 1H), 4.21 (dd, *J* = 4.7, 4.7 Hz, 1H), 3.82 (td, *J* = 9.9, 4.7 Hz, 1H), 3.71 – 3.55 (m, 7H), 3.50 (t, *J* = 8.2 Hz, 1H), 3.35 (s, 3H), 3.26 – 3.22 (m, 1H).

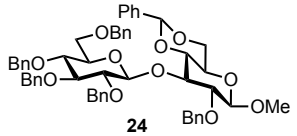
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.9, 138.6, 138.4, 138.2, 137.5, 129.0, 128.5, 128.5, 128.5, 128.4, 128.4, 128.2, 128.2, 128.1, 128.0, 127.9, 127.8, 127.6, 127.6, 126.3, 102.6, 101.6, 98.8, 85.1, 83.1, 80.6, 80.5, 78.1, 76.0, 75.7, 75.1, 75.0, 74.9, 73.9, 73.7, 69.2, 68.8, 62.3, 55.54. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report [14].

**α-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.47 – 7.10 (m, 28H), 6.96 (d, *J* = 7.3 Hz, 2H), 5.62 (d, *J* = 3.5 Hz, 1H), 5.50 (s, 1H), 5.03 (d, *J* = 10.8 Hz, 1H), 4.84 (d, *J* = 4.7 Hz, 1H), 4.82 (d, *J* = 5.0 Hz, 1H), 4.74 (d, *J* = 3.7 Hz, 1H), 4.69 (d, *J* = 11.2 Hz, 1H), 4.65 – 4.56 (m, 3H), 4.42 – 4.39 (m, 2H), 4.37 – 4.31 (m, 2H), 4.28 (dd, *J* = 10.2, 4.8 Hz, 1H), 4.23 (d, *J* = 10.1 Hz, 1H), 4.00 (t, *J* = 9.3 Hz, 1H), 3.91 (td, *J* = 9.9, 4.8 Hz, 1H), 1H), 3.82 (t, *J* = 9.4 Hz, 1H), 3.76 – 3.67 (m, 3H), 3.56 – 3.50 (m, 3H), 3.45 (s, 3H).

**$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 139.1, 139.0, 138.2, 138.0, 137.6, 137.3, 129.5, 128.8, 128.6, 128.6, 128.4, 128.4, 128.3, 128.3, 128.3, 128.1, 128.0, 127.7, 127.7, 127.5, 127.5, 127.4, 126.6, 102.3, 98.7, 96.3, 83.1, 81.8, 78.9, 78.2, 77.7, 75.7, 74.9, 73.6, 73.5, 72.9, 71.3, 70.0, 69.4, 68.3, 61.9, 55.5. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[14]

**Methyl 2-*O*-benzyl-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl)-(1→3)-4,6-*O*-benzylidene- β-D-glucopyranoside 24**




**24**

A solution of donor **1** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing

the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **13** (0.0496 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -30 °C with potassium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 19 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (12.5% ethyl acetate in hexane) to afford disaccharide **24** as an amorphous solid (0.0654 g, 0.073 mmol, 55% yield, β:α 11:1) when **4h** was used as the promoter or (0.0749 g, 0.084 mmol, 63% yield, β:α 10:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **24**.

**β-isomer**

**$[\alpha]_D^{22}$** = +2.2° (*c* 1.0, $CH_2Cl_2$);

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.50 – 7.01 (m, 30H), 5.47 (s, 1H), 5.00 (d, *J* = 11.1 Hz, 1H), 4.90 (d, *J* = 11.0 Hz, 1H), 4.87 (d, *J* = 7.8 Hz, 1H), 4.81 – 4.73 (m, 3H), 4.71 (d, *J* = 11.1 Hz, 1H), 4.64 (d, *J* = 10.4 Hz, 1H), 4.51 (d, *J* = 10.8 Hz, 1H), 4.47 (s, 2H), 4.42 (d, *J* = 7.6 Hz, 1H), 4.32 (dd, *J* = 10.4, 4.8 Hz, 1H), 4.10 (t, *J* = 8.9 Hz, 1H), 3.78 – 3.69 (m, 2H), 3.61 – 3.53 (m, 8H), 3.51 – 3.46 (m, 1H), 3.40 (td, J = 9.8, 4.9 Hz, 1H), 3.27 – 3.20 (m, 1H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 138.8, 138.7, 138.5, 138.4, 138.3, 137.5, 129.0, 128.5, 128.5, 128.4, 128.4, 128.3, 128.3, 128.2, 128.1, 128.1, 128.0, 128.0, 127.8, 127.7, 127.7, 127.6, 127.5, 126.3, 105.2, 102.6, 101.4, 85.0, 82.9, 79.7, 78.7, 78.1, 75.7, 75.1, 75.1, 75.0, 74.9, 73.7, 69.1, 68.90, 66.3, 57.5;

**LRMS (ESI) m/z**: calculated for $C_{55}H_{58}NaO_{11}$ (M+Na) = 917.39; found 917.45;

**HRMS (ESI) m/z**: calculated for $C_{55}H_{58}NaO_{11}$ (M+Na) = 917.3877; found 917.3912.

**α-isomer**

**$[\alpha]_D^{22}$** = +30.7° (*c* 0.6, $CH_2Cl_2$);

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.46 – 7.00 (m, 28H), 6.92 (d, *J* = 7.3 Hz, 2H), 5.58 (d, *J* = 3.6 Hz, 1H), 5.46 (s, 1H), 5.01 (d, *J* = 10.8 Hz, 1H), 4.87 (d, *J* = 10.0 Hz, 1H), 4.83

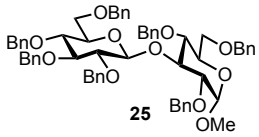
– 4.79 (m, 2H), 4.60 (d, *J* = 10.0 Hz, 1H), 4.56 (d, *J* = 12.3 Hz, 1H), 4.51 (d, *J* = 12.1 Hz, 1H), 4.46 (d, *J* = 7.7 Hz, 1H), 4.38 – 4.30 (m, 3H), 4.21 (d, *J* = 12.1 Hz, 1H), 4.15 – 4.06 (m, 2H), 3.97 (t, *J* = 9.4 Hz, 1H), 3.85 – 3.76 (m, 2H), 3.62 (s, 3H), 3.53 – 3.42 (m, 3H), 3.29 (dd, *J* = 10.8, 2.4 Hz, 1H), 3.24 (dd, *J* = 10.8, 1.8 Hz, 1H).

**$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 139.2, 139.0, 138.1, 138.1, 137.9, 137.8, 137.1, 129.6, 129.1, 128.6, 128.4, 128.4, 128.4, 128.3, 128.2, 128.0, 127.9, 127.9, 127.7, 127.6, 127.6, 127.6, 127.5, 126.5, 105.8, 102.2, 96.2, 82.4, 81.9, 80.3, 78.8, 77.6, 75.7, 75.5, 75.2, 75.1, 73.5, 71.3, 69.8, 69.1, 68.0, 65.9, 57.7;

**LRMS (ESI) m/z**: calculated for $C_{55}H_{58}NaO_{11}$ (M+Na) = 917.39; found 917.45;

**HRMS (ESI) m/z**: calculated for $C_{55}H_{58}NaO_{11}$ (M+Na) = 917.3877; found 917.3895.

**Methyl 2,4,6-tri-*O*-benzyl-3-O-(2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl)-α -D-glucopyranoside 25**



**25**

A solution of donor **1** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -15 °C or -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv., -15 °C) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv., -40 °C) in 2.0 mL of THF that had been pre-cooled to corresponding temperature. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **14** (0.0617 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -15 °C or -40 °C with potassium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 24 hours, the reaction was quenched with 0.1 mL of saturated, aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **25** (0.0630 g, 0.064 mmol, 48% yield, β:α 12:1) when **4h** was used as the promoter or (0.0708 g, 0.072 mmol, 54% yield, β:α 12:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **25**. The β

and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.45 – 6.99 (m, 35H), 5.10 – 5.03 (m, 3H), 5.00 (d, *J* = 10.8 Hz, 1H), 4.90 – 4.85 (m, 2H), 4.82 (d, *J* = 10.6 Hz, 1H), 4.65 (d, *J* = 11.6 Hz, 1H), 4.61 – 4.58 (m, 2H), 4.54 – 4.48 (m, 4H), 4.46 – 4.43 (m, 2H), 4.40 – 4.36 (m, 2H), 3.79 – 3.70 (m, 5H), 3.69 – 4.65 (m, 1H), 3.61 – 3.57 (m, 2H), 3.52 (dd, *J* = 9.5, 3.5 Hz, 1H), 3.47 (t, *J* = 8.5 Hz, 1H), 3.42 – 3.41 (m, 1H), 3.31 (s, 3H).

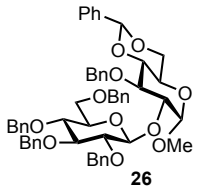
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.9, 138.8, 138.77, 138.4, 138.4, 138.2, 138.1, 128.5, 128.5, 128.3, 128.3, 128.2, 128.1, 128.0, 128.0, 127.8, 127.7, 127.7, 127.5, 127.4, 102.7, 97.9, 85.2, 83.4, 81.4, 78.4, 77.7, 76.2, 75.9, 75.2, 75.1, 74.9, 74.8, 73.7, 73.5, 69.7, 69.1, 68.8, 55.2. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[15]

**α-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.38 – 6.91 (m, 35H), 5.59 (d, *J* = 3.5 Hz, 1H), 4.94 (d, *J* = 11.5 Hz, 1H), 4.90 (d, *J* = 10.9 Hz, 1H), 4.83 – 4.79 (m, 2H), 4.70 – 4.65 (m, 2H), 4.63 – 4.56 (m, 5H), 4.52 (d, *J* = 11.4 Hz, 1H), 4.46 (d, *J* = 3.2 Hz, 1H), 4.43 (d, *J* = 4.3 Hz, 1H), 4.40 – 4.29 (m, 3H), 4.25 (t, *J* = 9.0 Hz, 1H), 4.05 (t, *J* = 9.4 Hz, 1H), 3.80 – 3.74 (m, 2H), 3.73 – 3.64 (m, 3H), 3.63 – 3.48 (m, 6H), 3.31 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.9, 138.5, 138.2, 138.1, 138.1, 128.9, 128.5, 128.5, 128.4, 128.4, 128.3, 128.2, 128.1, 128.0, 128.0, 127.9, 127.8, 127.7, 127.6, 127.6, 127.4, 127.1, 97.7, 97.5, 82.4, 79.9, 79.0, 78.8, 78.3, 75.6, 75.0, 73.7, 73.7, 73.6, 73.6, 73.4, 70.4, 69.7, 68.7, 68.6, 55.2. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[15]

**Methyl 3-*O*-benzyl-2-*O*-(2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl)-(1→2)-4,6-*O*-benzylidene-α-D-glucopyranoside 26**



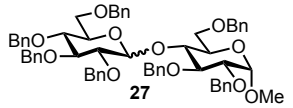

**26**

A solution of donor **1** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -15 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF that had been pre-cooled to -15 °C. The flask that contained the donor

was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **15** (0.0496 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -15 °C with sodium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 24 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (13% ethyl acetate in hexane) to afford disaccharide **26** as a single β-isomer (0.0535 g, 0.060 mmol, 45% yield) when **4h** was used as the promoter or (0.0499 g, 0.056 mmol, 42% yield) when **4i** was used as the promoter.

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.52 – 7.05 (m, 30H), 5.56 (s, 1H), 5.04 (d, *J* = 11.4 Hz, 1H), 4.96 (d, *J* = 3.6 Hz, 1H), 4.92 (d, *J* = 10.9 Hz, 1H), 4.83 – 4.74 (m, 5H), 4.65 (d, *J* = 10.8 Hz, 1H), 4.57 (d, *J* = 12.1 Hz, 1H), 4.53 – 4.49 (m, 2H), 4.32 (dd, *J* = 10.2, 4.8 Hz, 1H), 4.10 (t, *J* = 9.3 Hz, 1H), 3.90 (td, *J* = 10.1, 5.0 Hz, 1H), 3.85 (dd, *J* = 9.5, 3.6 Hz, 1H), 3.76 (t, *J* = 10.3 Hz, 1H), 3.67 – 3.50 (m, 6H), 3.45 – 3.38 (m, 4H).
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 138.8, 138.6, 138.2, 138.2, 137.6, 129.1, 128.5, 128.5, 128.4, 128.3, 128.3, 128.3, 128.2, 128.2, 128.1, 127.9, 127.8, 127.7, 127.6, 127.5, 126.2, 104.5, 101.5, 100.6, 84.9, 82.9, 82.1, 78.6, 78.3, 77.9, 75.8, 75.2, 75.2, 74.8, 74.7, 73.6, 69.4, 69.1, 62.4. The $^1$H NMR spectra coincide with the previous report.[16]

**Methyl 2,3,6-*O*-tribenzyl-4-*O*-(2,3,4,6-*O*-tetrabenzyl-β/α-D-glucopyranosyl)-α-D-glucopyranoside 27**



**27**

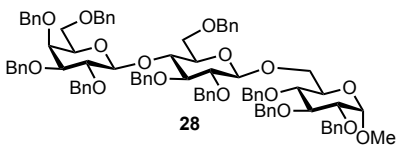
A solution of donor **1** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -30 °C or -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv., -30 °C) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv., -40 °C) in 2.0 mL of THF that had been pre-cooled to corresponding temperature. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated

with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **16** (0.0617 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -30 °C or -40 °C with potassium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 23 hours, the reaction was quenched with 0.1 mL of saturated, aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **27** (0.0499 g, 0.051 mmol, 38% yield, β:α 16:1) when **4h** was used as the promoter or (0.0525 g, 0.053 mmol, 40% yield, β:α 6:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **27** β and α products.

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.44 – 7.01 (m, 41H), 5.69 (d, *J* = 3.6 Hz, 0.2H), 5.09 (d, *J* = 11.3 Hz, 1H), 5.03 (d, *J* = 11.6 Hz, 0.2H), 4.89 – 4.85 (m, 1H), 4.83 – 4.72 (m, 7H), 4.70 (d, *J* = 12.1 Hz, 0.2H), 4.63 – 4.51 (m, 6H), 4.49 (d, *J* = 6.6 Hz, 1H), 4.46 – 4.34 (m, 5H), 4.27 (d, *J* = 12.1 Hz, 0.2H), 4.09 (d, *J* = 8.9 Hz, 0.2H), 4.06 (d, *J* = 4.4 Hz, 0.2H), 4.03 (d, *J* = 8.9 Hz, 0.2H), 3.96 (t, *J* = 9.5 Hz, 1H), 3.90 (t, *J* = 9.3 Hz, 0.2H), 3.87 – 3.80 (m, 2.6H), 3.71 (d, *J* = 10.8 Hz, 1H), 3.66 (d, *J* = 3.5 Hz, 0.2H), 3.64 (d, *J* = 3.6 Hz, 0.2H), 3.62 (d, *J* = 2.7 Hz, 0.4H), 3.59 (d, *J* = 9.3 Hz, 2H), 3.55 (d, *J* = 4.6 Hz, 0.5H), 3.53 (d, *J* = 4.6 Hz, 0.5H), 3.51 – 3.44 (m, 4H), 3.37 – 3.36 (m, 5H), 3.30 – 3.27 (m, 1H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.8, 138.8, 138.8, 138.7, 138.7, 138.6, 138.5, 138.4, 138.0, 128.6, 128.5, 128.5, 128.4, 128.4, 128.2, 128.2, 128.1, 127.9, 127.9, 127.9, 127.8, 127.7, 127.7, 127.4, 127.2, 126.9, 102.6, 98.6, 97.9, 96.8, 85.0, 83.0, 82.1, 80.6, 80.4, 79.7, 79.0, 78.2, 77.8, 75.7, 75.5, 75.4, 75.1, 74.9, 73.8, 73.6, 73.5, 73.5, 73.4, 73.3, 70.1, 69.7, 69.2, 68.4, 68.3, 68.1, 55.4, 55.30. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[10, 17]

**Methyl 2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranosyl-(1→4)-2,3,6-tri-*O*-benzyl-β-D-glucopyranosyl-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 28**



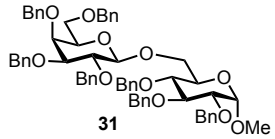
**28**

A solution of donor **10** (0.1944 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0464 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 4 hours, the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (19% ethyl acetate in hexane) to afford trisaccharide **28** as a single β-isomer (0.1002 g, 0.071 mmol, 71% yield) when **4h** was used as the promoter or (0.1281 g, 0.090 mmol, 90% yield) when **4i** was used as the promoter.

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.37 – 7.03 (m, 50H), 5.01 (d, *J* = 10.6 Hz, 1H), 4.97 – 4.95 (m, 2H), 4.90 (d, *J* = 11.0 Hz, 1H), 4.83 – 4.73 (m, 5H), 4.71 – 4.68 (m, 5H), 4.60 (d, *J* = 3.5 Hz, 1H), 4.57 – 4.46 (m, 3H), 4.44 (d, *J* = 7.7 Hz, 1H), 4.38 – 4.28 (m, 3H), 4.22 (d, *J* = 11.8 Hz, 1H), 4.14 (d, *J* = 9.1 Hz, 1H), 3.97 (t, *J* = 9.3 Hz, 1H), 4.93 – 4.89 (m, 2H), 3.83 – 3.68 (m, 4H), 3.66 (dd, *J* = 11.0, 4.8 Hz, 1H), 3.55 – 3.48 (m, 4H), 3.46 – 3.37 (m, 2H), 3.37 – 3.28 (m, 6H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.1, 139.1, 138.9, 138.8, 138.7, 138.6, 138.5, 138.2, 138.2, 128.5, 128.4, 128.4, 128.3, 128.3, 128.2, 128.2, 128.1, 128.1, 128.0, 127.9, 127.9, 127.9, 127.8, 127.7, 127.7, 127.6, 127.5, 127.5, 127.4, 127.4, 127.3, 127.1, 104.0, 102.8, 98.1, 83.2, 82.6, 82.0, 81.6, 80.0, 79.9, 78.0, 76.7, 75.7, 75.4, 75.4, 75.3, 75.0, 74.8, 74.7, 73.7, 73.4, 73.4, 73.1, 72.6, 70.0, 68.6, 68.4, 68.1, 55.2. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[18]

**Methyl 2,3,4-*O*-tribenzyl-6-*O*-(2,3,4,6-*O*-tetrabenzyl-β-D-galactopyranosyl)-α-D-glucopyranoside 31**



**31**

A solution of donor **29** (0.1080 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 3 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0309 g, 0.0667 mmol, 1 equiv.) in 0.7 mL of THF at -30 °C with sodium hexamethyldisilazane (0.067 mL, 0.0667 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.3 mL of THF, and this rinse was then added to the glycosylation reaction. After 8 hours, the reaction was quenched with 0.05 mL of saturated, aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **31** (0.0408 g, 0.041 mmol, 62% yield, β:α 12:1) when **4h** was used as the promoter or (0.0562 g, 0.057 mmol, 85% yield, β:α 10:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **31**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.47 – 7.07 (m, 35H), 4.97 – 4.89 (m, 3H), 4.77 – 4.70 (m, 6H), 4.64 (d, *J* = 12.1 Hz, 1H), 4.59 – 4.53 (m, 2H), 4.50 (d, *J* = 11.1 Hz, 1H), 4.45 – 4.37 (m, 2H), 4.30 (d, *J* = 7.7 Hz, 1H), 4.14 (dd, *J* = 10.7, 1.4 Hz, 1H), 3.97 (t, *J* = 9.3 Hz, 1H), 3.89 (d, *J* = 2.5 Hz, 1H), 3.87 – 3.79 (m, 2H), 3.64 – 3.58 (m, 2H), 3.56 (dd, *J* = 9.1, 5.4 Hz, 1H), 3.52 – 3.44 (m, 4H), 3.29 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.9, 138.9, 138.6, 138.5, 138.5, 138.3, 138.0, 131.4, 128.6, 128.5, 128.4, 128.4, 128.3, 128.3, 128.2, 128.1, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 127.5, 104.4, 98.0, 82.4, 82.2, 80.0, 79.4, 78.3, 75.8, 75.3, 74.9, 74.7, 73.6,

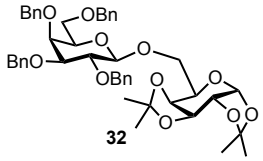
73.5, 73.5, 73.0, 70.1, 68.8, 68.7, 55.3. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[10]

**α-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.41 – 7.15 (m, 35H), 4.99 (d, *J* = 3.6 Hz, 1H), 4.96–4.92 (m, 2H), 4.84 (d, *J* = 11.0 Hz, 1H), 4.80 (d, *J* = 4.5 Hz, 1H), 4.78 (d, *J* = 5.6 Hz, 1H), 4.75 – 4.66 (m, 4H), 4.60 – 4.55 (m, 2H), 4.54 (d, *J* = 4.1 Hz, 1H), 4.52 (d, *J* = 3.5 Hz, 1H), 4.43 (d, *J* = 11.8 Hz, 1H), 4.36 (d, *J* = 11.8 Hz, 1H), 4.02 (dd, *J* = 3.6, 3.6 Hz, 1H), 3.98 – 3.94 (m, 2H), 3.92 – 3.88 (m, 2H), 3.80 – 3.71 (m, 3H), 3.58 (t, *J* = 9.2 Hz, 1H), 3.53 – 3.46 (m, 2H), 3.40 (dd, *J* = 9.6, 3.6 Hz, 1H), 3.29 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.1, 139.0, 138.9, 138.9, 138.6, 138.4, 138.2, 128.6, 128.5, 128.5, 128.4, 128.4, 128.3, 128.1, 128.1, 128.0, 127.8, 127.8, 127.7, 127.6, 127.5, 98.1, 98.1, 82.2, 80.4, 78.4, 78.2, 76.7, 75.8, 75.3, 75.1, 74.9, 73.5, 73.5, 73.0, 72.7, 70.5, 69.6, 69.1, 66.6, 55.2, 29.9. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[12]

**6-*O*-(2,3,4,6-*O*-tetrabenzyl-β-D-galactopyranosyl)-1,2;3,4-*O*-diisopropylidene-α-D-galactopyranoside 32**



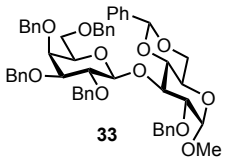

**32**

A solution of donor **29** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -15 °C or -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv., -15 °C) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv., -40 °C) in 2.0 mL of THF that had been pre-cooled to corresponding temperature. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **11** (0.0347 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -15 °C or -40 °C with sodium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 5 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column

chromatography (15% ethyl acetate in hexane) to afford disaccharide **32** as a single β-isomer (0.0604 g, 0.077 mmol, 58% yield) when **4h** was used as the promoter or (0.0957 g, 0.122 mmol, 92% yield) when **4i** was used as the promoter.

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.52 – 7.18 (m, 20H), 5.56 (d, *J* = 5.0 Hz, 1H), 5.05 (d, *J* = 11.0 Hz, 1H), 4.92 (d, *J* = 11.6 Hz, 1H), 4.78 (d, *J* = 11.9 Hz, 1H), 4.74 – 4.69 (m, 2H), 4.60 (d, *J* = 11.6 Hz, 1H), 4.57 (dd, *J* = 7.9, 2.3 Hz, 1H), 4.45 – 4.36 (m, 3H), 4.30 (dd, *J* = 5.0, 2.4 Hz, 1H), 4.21 (dd, *J* = 7.9, 1.7 Hz, 1H), 4.12 (dd, *J* = 10.6, 3.5 Hz, 1H), 4.08 – 4.06 (m, 1H), 3.88 (d, *J* = 2.7 Hz, 1H), 3.82 (dd, *J* = 9.7, 7.7 Hz, 1H), 3.68 (dd, *J* = 10.6, 7.5 Hz, 1H), 3.59 – 3.54 (m, 2H), 3.53 – 3.47 (m, 2H), 1.49 (s, 3H), 1.43 (s, 3H), 1.30 (d, *J* = 1.3 Hz, 6H).
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.1, 138.8, 138.7, 138.0, 128.7, 128.5, 128.5, 128.4, 128.2, 128.2, 128.0, 127.9, 127.6, 127.6, 127.4, 109.4, 108.7, 104.8, 96.5, 82.0, 79.2, 74.8, 74.6, 73.6, 73.6, 73.4, 73.2, 71.6, 70.9, 70.6, 69.7, 68.7, 67.5, 26.1, 26.1, 25.2, 24.5. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[10]

**Methyl 2-*O*-benzyl-3-*O*-(2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranosyl)-(1→3)-4,6-*O*-benzylidene-α-D-glucopyranoside 33**



**33**

A solution of donor **29** (0.1080 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF was cooled to -30 °C or -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 3 equiv., -30 °C) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 3 equiv., -40 °C) in 1.0 mL of THF that had been pre-cooled to corresponding temperature. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **12** (0.0248 g, 0.0667 mmol, 1 equiv.) in 0.7 mL of THF at -30 °C or -40 °C with potassium hexamethyldisilazane (0.067 mL, 0.0667 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.3 mL of THF, and this rinse was then added to the glycosylation reaction. The reaction was quenched with 0.05 mL of saturated, aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column

chromatography (15% ethyl acetate in hexane) to afford disaccharide **33** (4 hrs, 0.0435 g, 0.049 mmol, 73% yield, β:α 11:1) when **4h** was used as the promoter or (19 hrs, 0.0541 g, 0.061 mmol, 91% yield, β:α 5:1) when **4i** was used as the promoter. The selectivity was determined by $^{1}$H NMR integration of the anomeric signals of purified **33**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.54 – 7.04 (m, 30H), 5.50 (s, 1H), 5.03 (d, *J* = 11.0 Hz, 1H), 4.93 (d, *J* = 11.6 Hz, 1H), 4.80 – 4.74 (m, 3H), 4.71 – 4.66 (m, 2H), 4.60 (d, *J* = 11.6 Hz, 1H), 4.51 (d, *J* = 12.1 Hz, 1H), 4.44 (d, *J* = 3.8 Hz, 1H), 4.35 – 4.28 (m, 2H), 4.23 (d, *J* = 11.6 Hz, 1H), 4.19 (dd, *J* = 10.2, 4.6 Hz, 1H), 3.87 – 3.83 (m, 2H), 3.79 (td, *J* = 10.0, 4.6 Hz, 1H), 3.69 – 3.65 (m, 2H), 3.64 – 3.56 (m, 2H), 3.47 (dd, *J* = 9.7, 2.9 Hz, 1H), 3.39 (dd, *J* = 8.8, 5.4 Hz, 1H), 3.34 (s, 3H).

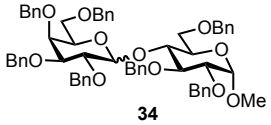
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 193.1, 139.2, 139.1, 138.8, 138.5, 138.1, 137.7, 137.4, 128.9, 128.5, 128.4, 128.3, 128.2, 128.0, 127.9, 127.8, 127.6, 127.5, 127.4, 126.3, 103.2, 101.2, 99.2, 82.8, 80.8, 80.3, 79.8, 77.0, 75.2, 74.6, 74.2, 73.6, 73.0, 72.9, 69.2, 68.7, 62.2, 55.4. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[19]

**α-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.46 – 6.94 (m, 30H), 5.61 (d, *J* = 3.5 Hz, 1H), 5.43 (s, 1H), 4.88 (d, *J* = 11.2 Hz, 1H), 4.85 (d, *J* = 11.8 Hz, 1H), 4.75 – 4.67 (m, 2H), 4.60 – 4.50 (m, 4H), 4.44 (d, *J* = 12.4 Hz, 1H), 4.40 – 4.30 (m, 4H), 4.21 (dd, *J* = 10.2, 4.8 Hz, 1H), 3.99 (dd, *J* = 9.8, 3.5 Hz, 1H), 3.96 – 3.90 (m, 2H), 3.83 (td, *J* = 9.9, 4.7 Hz, 1H), 3.73 (t, *J* = 9.4 Hz, 1H), 3.67 (t, *J* = 10.3 Hz, 1H), 3.63 – 3.56 (m, 2H), 3.54 (t, *J* = 8.6 Hz, 1H), 3.33 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.2, 139.1, 138.7, 138.5, 138.1, 137.7, 128.9, 128.5, 128.4, 128.4, 128.3, 128.3, 128.3, 128.2, 128.2, 128.0, 127.9, 127.8, 127.6, 127.6, 127.5, 127.4, 126.3, 103.2, 101.2, 99.2, 82.8, 80.8, 80.4, 79.8, 75.2, 74.6, 74.1, 73.7, 73.6, 73.0, 72.9, 69.2, 68.7, 62.2, 55.5. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[16a, 19]

**Methyl-*O*-(2,3,4,6-tetra-*O*-benzyl-β/α-D-galactopyranosyl)-(1→4)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside 34**




**34**

A solution of donor **29** (0.2160 g, 0.4 mmol, 3 equiv.) in 2.0 mL of THF was cooled to -30 °C or -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask

containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0884 g, 0.4 mmol, 3 equiv., -30 °C) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1246 g, 0.4 mmol, 3 equiv., -40 °C) in 1.0 mL of THF that had been pre-cooled to corresponding temperature. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **16** (0.0618 g, 0.133 mmol, 1 equiv.) in 1.4 mL of THF at -30 °C or -40 °C with potassium hexamethyldisilazane (0.133 mL, 0.133 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.6 mL of THF, and this rinse was then added to the glycosylation reaction. After 20 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **34** (0.0879 g, 0.089 mmol, 67% yield, β:α 6:1) when **4h** was used as the promoter or (0.0932 g, 0.094 mmol, 71% yield, β:α 5:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **34**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

The procedure below is the glycosylation promoted by 4-bromobenzenesulfonyl chloride **4g** and disaccharide **34** was generated in 51% yield, β:α 11:1.

A solution of donor **29** (0.1621 g, 0.3 mmol, 4 equiv.) in 1.5 mL of THF was cooled to -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.3 mL, 0.3 mmol, 4 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 4-bromobenzenesulfonyl chloride **4g** (0.0762g, 0.3 mmol, 4 equiv.) in 1.5 mL of THF that had been pre-cooled to -40 °C. The flask that contained the donor was then rinsed with an additional 0.7 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **16** (0.0348 g, 0.075 mmol, 1 equiv.) in 0.8 mL of THF at -40 °C with potassium hexamethyldisilazane (0.075 mL, 0.075 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.4 mL of THF, and this rinse was then added to the glycosylation reaction. After 46 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$),

filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (15% ethyl acetate in hexane) to afford disaccharide **34** (0.0374 g, 0.038 mmol, 51% yield, β:α 11:1). The selectivity was determined by $^{1}$H NMR integration of the anomeric signals of purified **34**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.49 – 7.02 (m, 35H), 5.03 (d, *J* = 10.6 Hz, 1H), 4.97 (d, *J* = 11.4 Hz, 1H), 4.87 – 4.60 (m, 7H), 4.56 – 4.51 (m, 3H), 4.39 – 4.27 (m, 3H), 4.24 (d, *J* = 11.8 Hz, 1H), 3.92 – 3.88 (m, 2H), 3.85 – 3.78 (m, 2H), 3.74 (dd, *J* = 9.6, 7.8 Hz, 1H), 3.60 (d, *J* = 9.6 Hz, 1H), 3.56 – 3.41 (m, 3H), 3.41 – 3.27 (m, 6H).

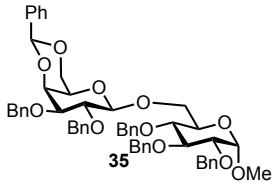
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.5, 139.1, 139.0, 138.6, 138.6, 138.3, 138.2, 128.4, 128.4, 128.3, 128.2, 128.2, 128.2, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 127.5, 127.4, 127.4, 127.4, 127.0, 102.8, 98.5, 82.6, 80.3, 80.1, 79.0, 76.7, 75.5, 75.3, 74.7, 73.8, 73.7, 73.5, 73.2, 73.1, 72.6, 70.1, 68.3, 68.1, 55.3. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[17]

**α-isomer**

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.39 – 7.02 (m, 35H), 5.75 (d, *J* = 3.8 Hz, 1H), 4.97 (d, *J* = 11.5 Hz, 1H), 4.86 (d, *J* = 11.4 Hz, 1H), 4.81 (d, *J* = 11.5 Hz, 1H), 4.72 – 4.49 (m, 9H), 4.42 (d, *J* = 12.3 Hz, 1H), 4.30 (d, *J* = 11.6 Hz, 1H), 4.23 (d, *J* = 11.6 Hz, 1H), 4.06 (t, *J* = 9.1 Hz, 1H), 4.01 – 3.91 (m, 3H), 3.88 – 3.77 (m, 3H), 3.70 (dd, *J* = 10.6, 4.6 Hz, 1H), 3.64 (dd, *J* = 10.6, 2.2 Hz, 1H), 3.54 (dd, *J* = 9.6, 3.5 Hz, 1H), 3.48 (t, *J* = 8.2 Hz, 1H), 3.43 (dd, *J* = 8.8, 5.6 Hz, 1H), 3.37 (s, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.7, 138.4, 138.3, 138.0, 128.4, 128.3, 128.3, 128.3, 128.2, 128.2, 128.2, 127.9, 127.8, 127.7, 127.6, 127.5, 127.4, 127.4, 127.4, 127.0, 126.8, 97.8, 97.5, 82.0, 80.2, 79.2, 75.7, 74.8, 74.7, 74.3, 73.8, 73.4, 73.4, 73.1, 72.9, 72.8, 69.9, 69.5, 69.5, 68.7, 55.1. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[17]

**Methyl**
**4-*O*-(2',3'-di-*O*-benzyl-4',6'-*O*-benzylidene-β-D-galactopyranosyl)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 35**



**35**

A solution of donor **30** (0.0976 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 3 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0309 g, 0.0667 mmol, 1 equiv.) in 0.7 mL of THF at -30 °C with sodium hexamethyldisilazane (0.067 mL, 0.0667 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.3 mL of THF, and this rinse was then added to the glycosylation reaction. The reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (25% ethyl acetate in hexane) to afford disaccharide **35** (24 hrs, 0.0262 g, 0.029 mmol, 44% yield, β:α 9.5:1) when **4h** was used as the promoter or (7 hrs, 0.0382 g, 0.043 mmol, 64% yield, β:α 6:1) when **4i** was used as the promoter. The selectivity was determined by $^1$H NMR integration of the anomeric signals of purified **35**. The β and α products did not separate significantly on silica gel, and care was taken to isolate the entire chromatographic band.

**β-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.61 – 7.01 (m, 30H), 5.47 (s, 1H), 4.97 (d, *J* = 10.9 Hz, 1H), 4.92 (d, *J* = 10.8 Hz, 1H), 4.81 – 4.71 (m, 6H), 4.64 (d, *J* = 12.1 Hz, 1H), 4.61 (d, *J* = 3.4 Hz, 1H), 4.52 (d, *J* = 11.2 Hz, 1H), 4.30 (d, *J* = 7.8 Hz, 1H), 4.26 (d, *J* = 12.2 Hz, 1H), 4.18 (d, *J* = 10.9 Hz, 1H), 4.07 (d, *J* = 3.4 Hz, 1H), 4.00 – 3.96 (m, 2H), 3.90 – 3.82 (m, 2H), 3.68 (dd, *J* = 11.1, 5.0 Hz, 1H), 3.54 – 3.50 (m, 3H), 3.34 (s, 3H), 3.21 (s, 1H).

**$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 139.1, 139.0, 138.7, 138.6, 138.3, 138.1, 129.0, 128.6, 128.5, 128.5, 128.4, 128.3, 128.2, 128.1, 128.1, 128.0, 127.9, 127.8, 127.8, 127.6, 127.5, 126.6, 104.4, 101.4, 98.2, 82.2, 80.0, 79.5, 78.3, 78.3, 75.8, 75.4, 75.0, 73.9, 73.5, 72.0, 70.1, 69.3, 68.9, 66.6, 55.4. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[20]

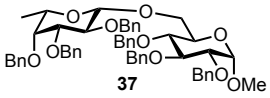
**α-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.57 – 7.15 (m, 30H), 5.44 (s, 1H), 5.04 (d, *J* = 3.4 Hz, 1H), 4.97 (d, *J* = 10.8 Hz, 1H), 4.88 (d, *J* = 11.4 Hz, 1H), 4.81 – 4.64 (m, 6H), 4.58 (d,

*J* = 12.1 Hz, 1H), 4.55 – 4.49 (m, 2H), 4.12 – 4.08 (m, 2H), 4.05 (dd, *J* = 10.1, 3.4 Hz, 1H), 3.97 (t, *J* = 9.3 Hz, 1H), 3.92 (dd, *J* = 10.1, 3.4 Hz, 1H), 3.86 (d, *J* = 11.1 Hz, 1H), 3.80 – 3.74 (m, 1H), 3.73 (d, *J* = 5.0 Hz, 1H), 3.69 (d, *J* = 11.0 Hz, 1H), 3.56 (t, *J* = 9.3 Hz, 1H), 3.48 (s, 1H), 3.43 (dd, *J* = 9.6, 3.6 Hz, 1H), 3.28 (s, 3H).

**$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 139.1, 139.0, 138.9, 138.7, 138.4, 138.1, 129.0, 128.6, 128.5, 128.4, 128.4, 128.3, 128.2, 128.0, 127.9, 127.7, 127.7, 127.7, 127.6, 126.5, 101.2, 98.6, 98.1, 82.3, 80.3, 78.2, 75.8, 75.2, 75.0, 75.0, 73.5, 73.0, 72.0, 70.3, 69.6, 66.7, 62.8, 55.2. The $^{1}$H NMR and $^{13}$C NMR spectra coincide with the previous report.[20]

**Methyl-(2,3,4-tri-*O*-benzyl-β-L-fucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside 37**



**37**

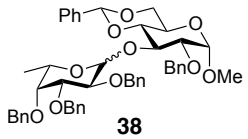
A solution of donor **36** (0.0868 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 3 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 3 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 3 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mLof THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **2** (0.0309 g, 0.0667 mmol, 1 equiv.) in 0.7 mL of THF at -30 °C with sodium hexamethyldisilazane (0.067 mL, 0.0667 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.3 mL of THF, and this rinse was then added to the glycosylation reaction. After 8 hours, the reaction was quenched with 0.05 mL of saturated, aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (18% ethyl acetate in hexane) to afford disaccharide **37** as a single β-isomer (0.0262 g, 0.030 mmol, 45% yield) when **4h** was used as the promoter or (0.0321 g, 0.036 mmol, 54% yield) when **4i** was used as the promoter. (With the promoter 4-bromobenzenesulfonyl chloride **4g**, the disaccharide **37** was generated as a single β-isomer in 60% yield).

**$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.45 – 7.14 (m, 30H), 4.99 – 4.95 (m, 3H), 4.90 – 4.61 (m, 9H), 4.61 – 4.52 (m, 2H), 4.40 (d, *J* = 7.5 Hz, 1H), 4.21 – 4.12 (m, 1H), 3.97 (t, *J*

= 9.1 Hz, 1H), 3.84 – 3.70 (m, 3H), 3.66 (t, *J* = 9.3 Hz, 1H), 3.56 – 3.46 (m, 2H), 3.46 – 3.39 (m, 2H), 3.32 (s, 3H), 1.16 (d, *J* = 6.1 Hz, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 139.0, 138.8, 138.8, 138.5, 138.3, 128.4, 128.4, 128.4, 128.3, 128.3, 128.2, 128.2, 128.2, 128.1, 128.0, 127.9, 127.8, 127.6, 127.6, 127.5, 127.5, 127.4, 103.8, 98.1, 82.5, 82.0, 80.3, 79.5, 77.8, 76.7, 75.7, 75.1, 75.1, 74.6, 73.5, 73.2, 70.4, 70.1, 67.5, 55.1, 16.9. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[21]

**Methyl-(2,3,4-tri-*O*-benzyl-β/α-L-fucopyranosyl)-(1→3)-2-*O*-benzyl-4,6-*O*-benzylidine-α-D-glucopyranoside 38**




**38**

A solution of donor **36** (0.1737 g, 0.4mmol, 4 equiv.) in 2.0 mL of THF was cooled to -40 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.4 mL, 0.4 mmol, 4 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 4-fluorobenzenesulfonyl chloride **4m** (0.0776g, 0.4 mmoL) in 2.0 mL of THF that had been pre-cooled to -40 °C. The flask that contained the donor was then rinsed with an additional 1.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -40 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **12** (0.0372 g, 0.1 mmol, 1 equiv.) in 0.8 mL of THF at -40 °C with potassium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 72 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 20 mL). The combined organic phase was washed with brine (40 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (17% ethyl acetate in hexane) to afford disaccharide **38** (34% yield, β:α 11:1). The selectivity was determined by crude $^1$H NMR analysis.

This procedure was followed when other sulfonates were used as the promoters.

**β-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.63 – 7.06 (m, 25H), 5.28 (s, 1H), 5.01 (d, *J* = 11.7 Hz, 1H), 4.95 – 4.89 (m, 2H), 4.84 (d, *J* = 7.7 Hz, 1H), 4.81 – 4.68 (m, 4H), 4.67 – 4.62 (m, 2H), 4.39 (t, *J* = 9.1 Hz, 1H), 4.24 (dd, *J* = 10.2, 4.8 Hz, 1H), 3.82 – 3.76 (m, 2H),

3.61 (t, $J$ = 10.3 Hz, 1H), 3.58 – 3.42 (m, 4H), 3.41 – 3.32 (m, 4H), 1.18 (d, $J$ = 6.3 Hz, 3H).

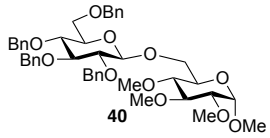
**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.5, 139.0, 138.8, 138.6, 137.4, 128.6, 128.3, 128.3, 128.1, 128.0, 128.0, 127.7, 127.6, 127.6, 127.5, 127.4, 127.1, 126.1, 103.3, 101.1, 99.5, 82.5, 82.3, 80.3, 78.1, 77.2, 76.0, 74.8, 74.7, 73.7, 73.0, 70.3, 69.1, 61.8, 55.3, 17.0. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[21]

**α-isomer**

**$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.57 – 7.00 (m, 25H), 5.51 (d, $J$ = 3.7 Hz, 1H), 5.46 (s, 1H), 4.88 – 4.81 (m, 2H), 4.75 – 4.61 (m, 4H), 4.61 – 4.52 (m, 2H), 4.49 (d, $J$ = 3.6 Hz, 1H), 4.30 (t, $J$ = 9.4 Hz, 1H), 4.26 – 4.17 (m, 2H), 4.03 (dd, $J$ = 10.2, 3.7 Hz, 1H), 3.96 (dd, $J$ = 10.2, 2.7 Hz, 1H), 3.83 (td, $J$ = 10.0, 4.7 Hz, 1H), 3.73 – 3.63 (m, 2H), 3.60 (t, $J$ = 9.5 Hz, 1H), 3.51 – 3.50 (m, 1H), 3.33 (s, 3H), 0.80 (d, $J$ = 6.4 Hz, 3H).

**$^{13}$C NMR** (125 MHz, $CDCl_3$) δ 139.0, 138.8, 138.5, 138.3, 137.5, 129.1, 128.4, 128.3, 128.3, 128.2, 128.1, 127.9, 127.7, 127.6, 127.4, 127.3, 127.3, 126.2, 101.8, 98.8, 97.5, 81.1, 80.0, 79.8, 18.0, 75.9, 74.8, 73.2, 72.9, 72.8, 72.5, 69.2, 66.0, 62.4, 55.3, 16.3. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[21]

## Methyl (2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-methyl-α-D-glucopyranoside 40




A solution of donor **1** (0.1080 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 2 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of either *p*-nitrobenzenesulfonyl chloride **4h** (0.0442 g, 0.2 mmol, 2 equiv.) or 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 2 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 °C. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **39** (0.0236 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF at -30 °C with sodium hexamethyldisilazane (0.1 mL, 0.1 mmol, 1 equiv.) and stirring for 10 minutes.). The flask that had contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 3 hours,

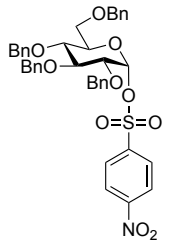
the reaction was quenched with 0.05 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by silica gel flash column chromatography (25% ethyl acetate in hexane) to afford disaccharide **40** as a single β-isomer (0.0682 g, 0.090 mmol, 90% yield) when **4h** was used as the promoter or (0.0691 g, 0.091 mmol, 91% yield) when **4i** was used as the promoter. The selectivity was determined by crude $^1$H NMR analysis.

**$^1$H NMR** (500 MHz, CDCl3) δ 7.52 – 7.03 (m, 21H), 5.10 (d, *J* = 11.0 Hz, 1H), 4.99 (d, *J* = 10.9 Hz, 1H), 4.91– 4.82 (m, 4H), 4.70– 4.60 (m, 3H), 4.55 (d, *J* = 7.8 Hz, 1H), 4.32 – 4.24 (m, 1H), 3.89 – 3.71 (m, 5H), 3.71 – 3.64 (m, 4H), 3.64 – 3.51 (m, 9H), 3.43 (s, 3H), 3.28 (dd, *J* = 9.6, 3.6 Hz, 1H), 3.22 (t, *J* = 9.2 Hz, 1H).

**$^{13}$C NMR** (125 MHz, CDCl3) δ 138.7, 138.5, 138.3, 138.2, 128.5, 128.4, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 127.6, 104.0, 97.4, 84.9, 83.5, 82.3, 81.9, 79.9, 78.0, 75.8, 75.2, 75.1, 74.9, 73.5, 69.9, 69.1, 68.9, 60.8, 60.4, 59.0, 55.2. The $^1$H NMR and $^{13}$C NMR spectra coincide with the previous report.[22]

## 4.2 Experimental data for variable temperature NMR study

### *p*-nitrobenzenesulfonyl 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

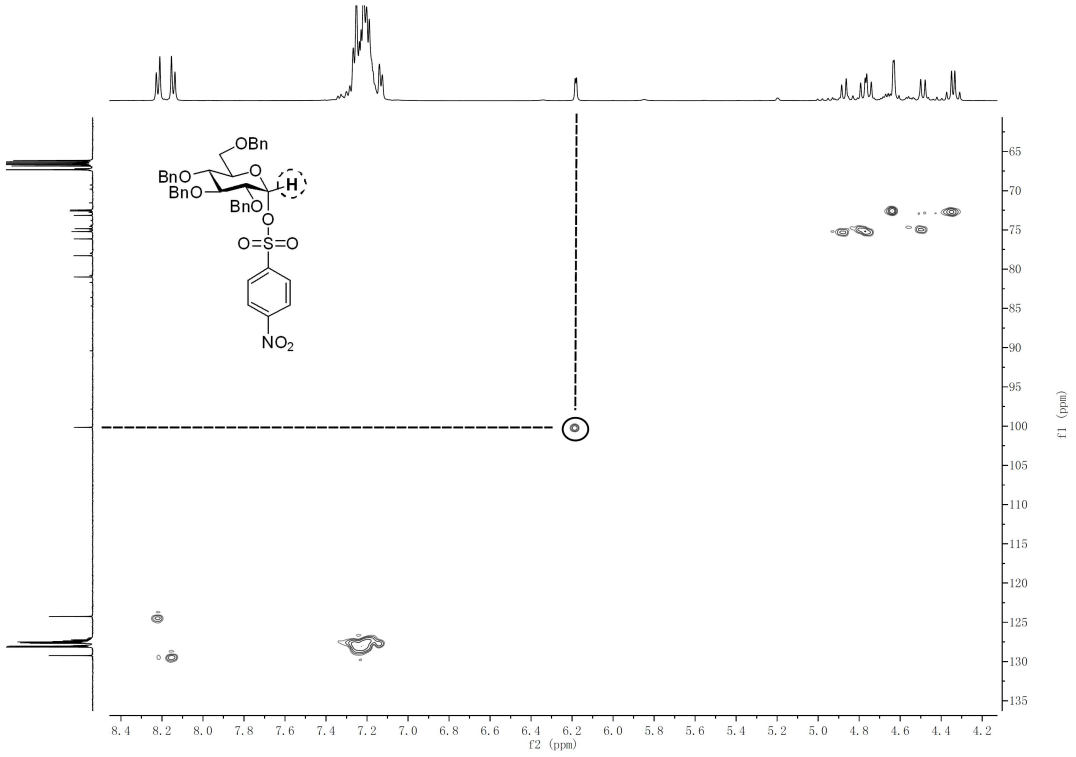



A solution of donor **1** (0.0540 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF-$d_8$ was cooled to -30 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.1 mL, 0.1 mmol, 1 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of *p*-nitrobenzenesulfonyl chloride **4h** (0.0221 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF-$d_8$ that had been pre-cooled to -30 °C. The solution maintained at -30 °C for 2 hrs, transferred by syringe to a pre-cooled 5 mm Low Pressure/Vacuum Valve NMR tube, and promptly inserted into the NMR instrument probe pre-cooled to -30 °C for $^1$H NMR, $^{13}$C NMR, and 2D-Gradient HSQC data acquisition in Figure S1. The temperature was maintained for 1 hour, then warmed by 15 degrees every 15 minutes. At each 15 mins interval, the $^1$H NMR spectrum was recorded.

**$^1$H NMR** (500 MHz, THF-$d_8$) δ 8.22 (d, *J* = 8.6 Hz, 2H), 8.15 (d, *J* = 8.6 Hz, 2H), 7.29 – 7.11 (m, 20H), 6.18 (d, *J* = 3.2 Hz, 1H), 4.87 (d, *J* = 11.1 Hz, 1H), 4.79 – 4.74 (m, 2H), 4.63 – 4.62 (m, 2H), 4.49 (d, *J* = 11.0 Hz, 1H), 4.37 – 4.31 (m, 2H), 3.79 (t, *J* = 9.3 Hz, 1H), 3.70 (dd, *J* = 9.6, 3.1 Hz, 1H), 3.64 (t, *J* = 9.5 Hz, 1H), 3.53 (s, 1H), 3.50 – 3.49 (m, 1H), 3.10 (d, *J* = 10.3 Hz, 1H).

**$^{13}$C NMR** (125 MHz, THF-$d_8$) δ 150.4, 143.0, 138.8, 138.3, 138.1, 137.8, 129.1, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 127.5, 127.4, 127.4, 127.4, 127.3, 127.3, 127.3, 127.2, 127.1, 127.1, 124.1, 100.0, 80.8, 78.1, 76.0, 75.0, 74.7, 73.0, 72.4, 72.3.

(a)




(b)

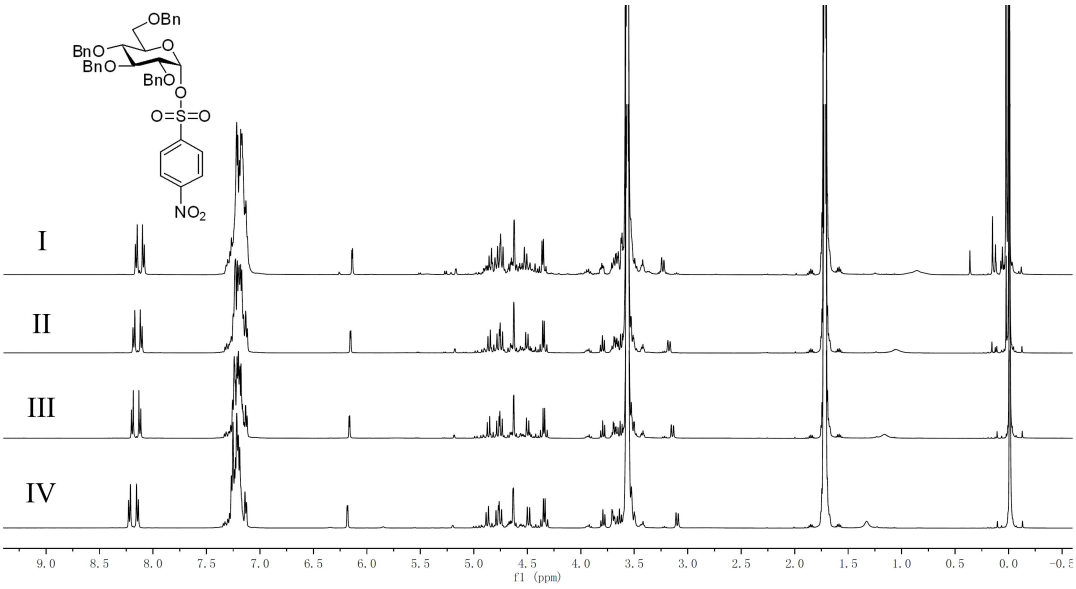
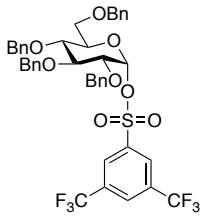



**Figure S1.** VT-NMR mechanistic studies. (a) 2D Gradient HSQC NMR spectrum of α-glucosyl nosylate at -30 ºC. (b) $^{1}H$ NMR spectra to evaluate the stability of the α -glucosyl nosylate in THF-$d_8$ at: (I) 25 ºC, (II) 0 ºC, (III) -15 ºC, (IV) -30 ºC.

**3,5-bis(trifluoromethyl)benzenesulfonyl-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside**

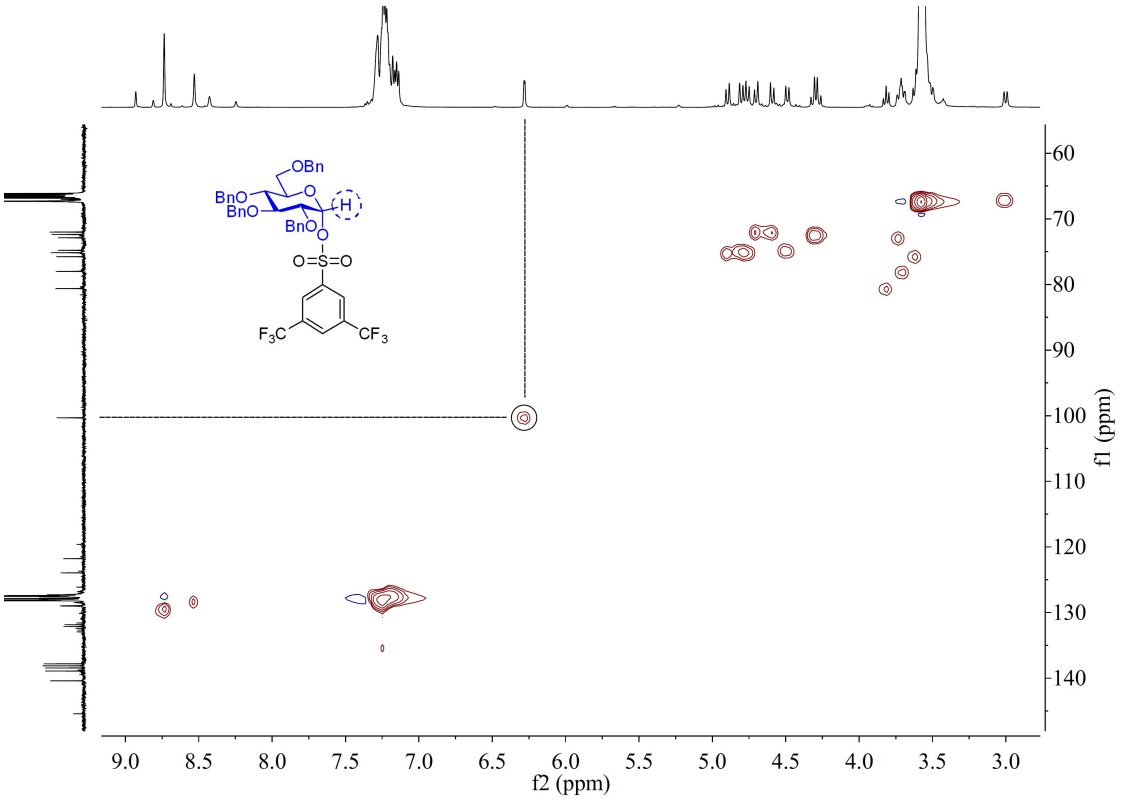



A solution of donor **1** (0.0540 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF-$d_8$ was cooled to -60 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.1 mL, 0.1 mmol, 1 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0312 g, 0.1 mmol, 1 equiv.) in 0.5 mL of THF-$d_8$ that had been pre-cooled to -60 °C. The solution maintained at -60 °C for 2 hrs, transferred by syringe to a pre-cooled 5 mm Low Pressure/Vacuum Valve NMR tube, and promptly inserted into the NMR instrument probe pre-cooled to -60 °C for $^1$H NMR, $^{13}$C NMR, and 2D-Gradient HSQC data acquisition in Figure S2. The temperature was maintained for 30 minutes, then warmed by 20 degrees every 20 minutes. At each 15 mins interval, the $^1$H NMR spectrum was recorded.

**$^1$H NMR** (500 MHz, THF-$d_8$) δ 8.74 (s, 2H), 8.53 (s, 1H), 7.34 – 7.08 (m, 20H), 6.28 (d, *J* = 3.3 Hz, 1H), 4.90 (d, *J* = 11.2 Hz, 1H), 4.81 – 4.75 (m, 2H), 4.70 (d, *J* = 11.2 Hz, 1H), 4.59 (d, *J* = 11.3 Hz, 1H), 4.49 (d, *J* = 10.8 Hz, 1H), 4.33 – 4.36 (m, 2H), 3.82 (t, *J* = 9.4 Hz, 1H), 3.77 – 3.66 (m, 3H), 3.50 – 3.66 (m, 1H), 3.00 (d, *J* = 10.5 Hz, 1H).

**$^{13}$C NMR** (125 MHz, THF-$d_8$) δ 140.4, 138.9, 138.5, 138.1, 137.8, 132.1, 131.9, 129.0, 128.2, 128.2, 128.1, 128.1, 128.0, 127.9, 127.6, 127.6, 127.5, 127.5, 127.4, 127.4, 127.3, 127.3, 124.0, 121.8, 100.3, 80.6, 78.0, 75.8, 75.2, 74.8, 72.9, 72.4, 72.0.

(a)




(b)

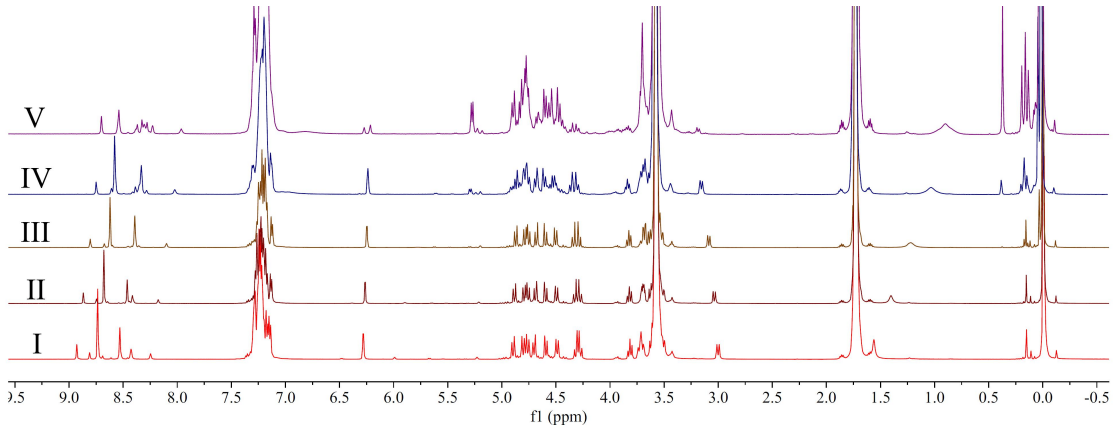
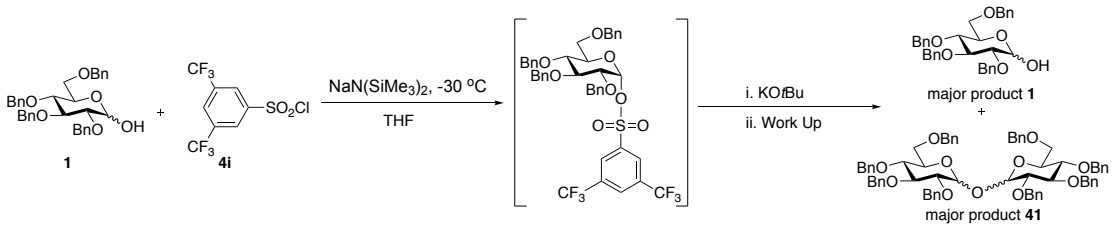



**Figure S2.** VT-NMR mechanistic studies. (a) 2D Gradient HSQC NMR spectrum of α-glucosyl 3,5-bis(trifluoromethyl)-benzenesulfonate at -60 ºC. (b) $^{1}$H NMR spectra to evaluate the stability of the α-glucosyl 3,5-bis(trifluoromethyl)-benzenesulfonate in THF-$d_8$ at: (I) -60 ºC, (II) -40 ºC, (III) -20 ºC, (IV) 0 ºC, (V) 25 ºC

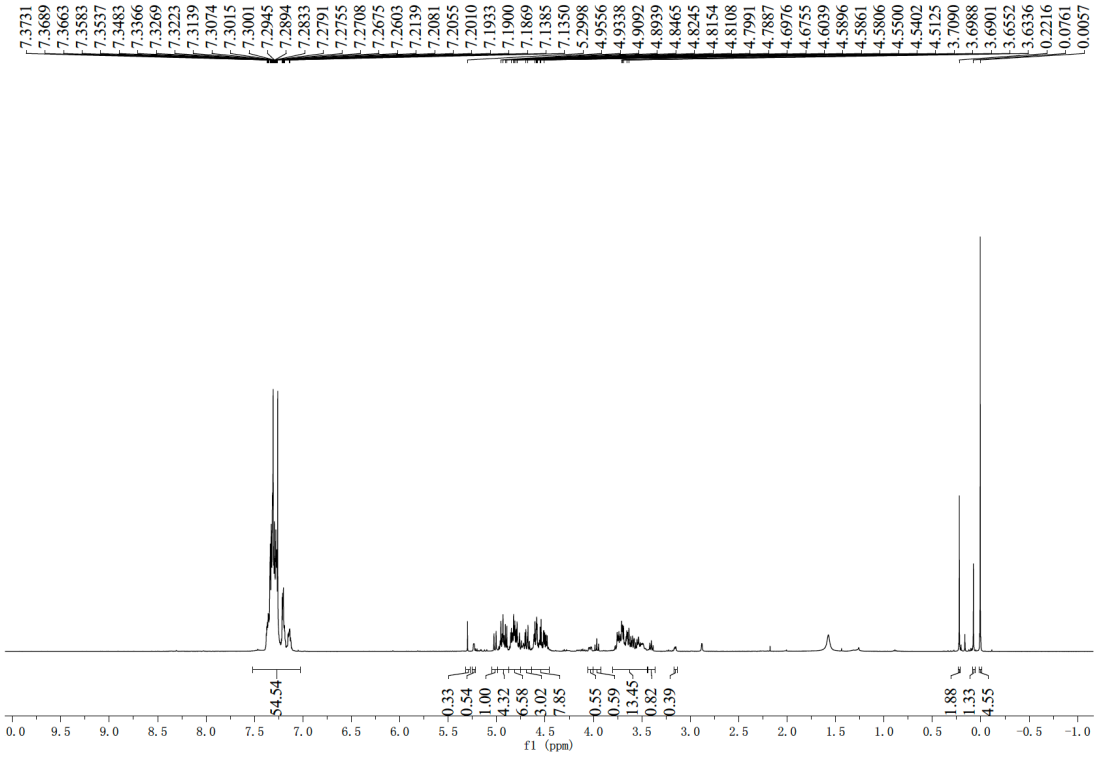
## 4.3 Activated sulfonate donor for elimination reaction test




A solution of donor **1** (0.1080 g, 0.2 mmol, 1 equiv.) in 1.0 mL of THF was cooled to -30 ºC and treated with sodium hexamethyldisilazane (1 M in THF, 0.2 mL, 0.2 mmol, 1 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0623 g, 0.2 mmol, 1 equiv.) in 1.0 mL of THF that had been pre-cooled to -30 ºC. The flask that contained the donor was then rinsed with an additional 0.5 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at -30 ºC, it was treated with potassium *tert*-butoxide (0.0224g, 0.2 mmol, 1 equiv.). After 4 hrs. The reaction was quenched with 0.2 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 10 mL). The combined organic phase was washed with brine (20 mL) and then dried ($Na_2SO_4$). An aliquot of (1.0 mL) of this solution was removed for NMR and LCMS analysis. The E2 elimination product was not found in the crude $^1$H NMR and LCMS according to the literature.[23]

(Potassium *tert*-butoxide was prepared by heating at 150–160ºC/2mm for 1h to remove the *tert*-BuOH according to the literature method.[24])

(a) $^{1}$H NMR (500 MHz, $CDCl_3$)



(b)

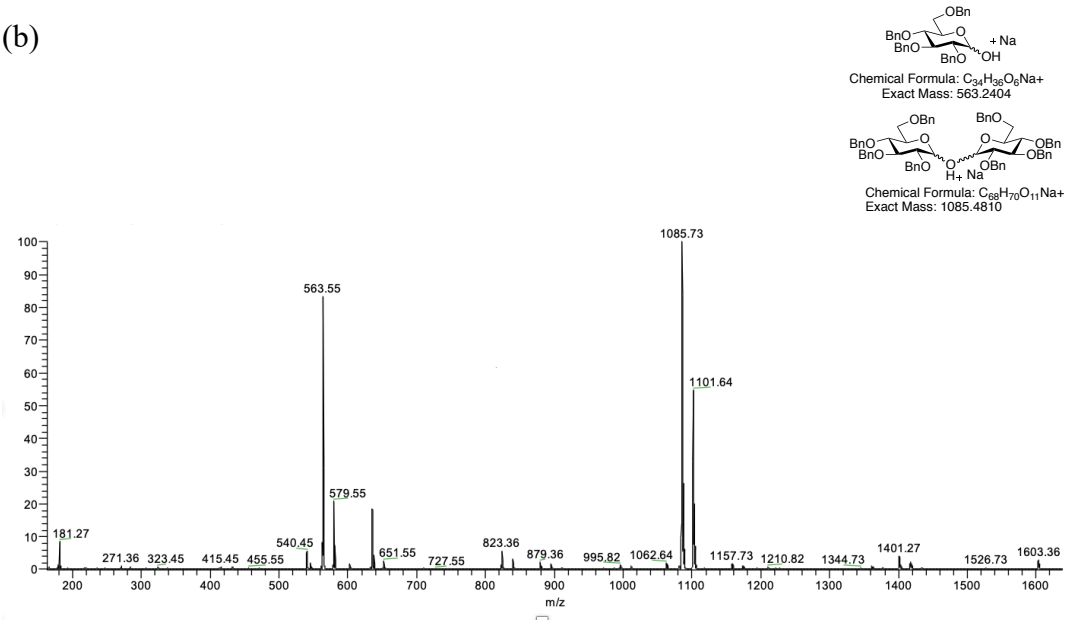
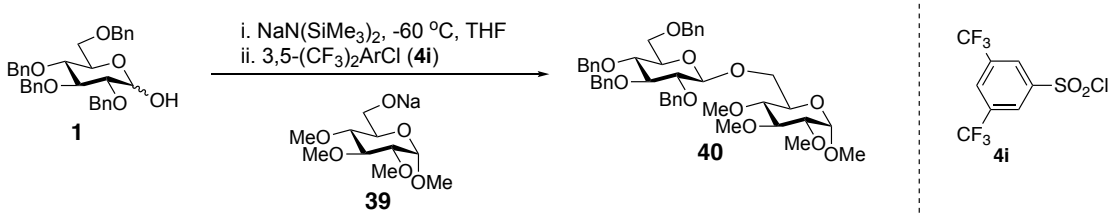



**Figure S3.** (a) the $^{1}$H NMR for the aliquot of reaction in $CDCl_3$; (b) the LCMS for the aliquot.

## 5. KIE Measurements

### 5.1 $^{13}$C KIE measurements




Procedure for the glycosylation of perbenzylated glucosyl donor **1** with permethylated acceptor **39**.

**High conversion:**

A solution of donor **1** (0.2701 g, 0.5 mmol, 1 equiv.) in 2.5 mL of THF was cooled to –60 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.5 mL, 0.5 mmol, 1 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1559 g, 0.5 mmol, 1 equiv.) in 2.5 mL of THF that had been pre-cooled to –60 °C. The flask that contained the donor was then rinsed with an additional 1.3 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at –60 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **39** (0.2361 g, 1.0 mmol, 2 equiv.) in 4.0 mL of THF at –60 °C with sodium hexamethyldisilazane (1.0 mL, 1.0 mmol, 2 equiv.). and stirring for 10 minutes.). The flask that contained the acceptor was rinsed with 2.0 mL of THF, and this rinse was then added to the glycosylation reaction. After 6 hours, the reaction was quenched with 0.5 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (60 mL) and then dried ($Na_2SO_4$). Internal standard 1-bromo-2,4,6-tri-*tert*-butylbenzene was added to the crude sample. An aliquot of 0.4 mL was removed for NMR analysis. The rest of the crude product was purified by silica gel flash column chromatography (30% ethyl acetate in hexane) to afford disaccharide **40** exclusively as the β-isomer (0.3443 g, 0.454 mmol, 91% yield relative to donor **1**). This reaction was conducted twice. The second time, the yield of this reaction was 90% relative to donor **1**.

**Partial conversion:**

A solution of donor **1** (0.6483 g, 1.2 mmol, 4 equiv.) in 6.0 mL of THF was cooled to –60 °C and treated with sodium hexamethyldisilazane (1 M in THF, 1.2 mL, 1.2 mmol, 4 equiv.). After 10 minutes, this solution was transferred by syringe to a flask containing

the solution of 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.3743 g, 1.2 mmol, 4 equiv.) in 6.0 mL of THF that had been pre-cooled to –60 ºC. The flask that contained the donor was then rinsed with an additional 3.0 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at –60 ºC, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **39** (0.0708 g, 0.3 mmol, 1 equiv.) in 1.5 mL of THF at –60 ºC with sodium hexamethyldisilazane (0.3 mL, 0.3 mmol, 1 equiv.). and stirring for 10 minutes.). The flask that contained the acceptor was rinsed with 1.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 2 hours, the reaction was quenched with 1.2 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 20 mL). The combined organic phase was washed with brine (80 mL) and then dried ($Na_2SO_4$). Internal standard 1-bromo-2,4,6-tri-*tert*-butylbenzene was added to the crude sample. An aliquot of 1.0 mL was removed for NMR analysis. The rest of the crude product was purified by silica gel flash column chromatography (30% ethyl acetate in hexane) to afford disaccharide **40** exclusively as the β-isomer (0.2041 g, 0.269 mmol, 22% yield relative to donor **1**). This reaction was conducted twice. The second time, the yield of this reaction was 23% relative to donor **1**.

Note: spectra for $^{13}C$ KIE studies were taken in 2.3:1 $CDCl_3$:$C_6D_6$ to avoid peak overlap at the C5 resonance of the donor. The samples for $^{13}C$ KIE studies were prepared by dissolving 150 mg of **40** in 0.6 mL of 2.3:1 $CDCl_3$:$C_6D_6$ with 0.5mM of $Cr(acac)_3$ as a relaxation reagent.

**Tables S6**–**S8** of Integrals for $^{13}C$ KIE Measurements

**Table S6**.

| **sample name (raw integral)** | **C1** | **C2** | **C3** | **C4** | **C5** | **blocks*** |
|---|---|---|---|---|---|---|
| sample 1 (full conversion 1) | 11.2474 | 10.2324 | 10.3012 | 10.3829 | 10.1132 | 200 |
| sample 2 (full conversion 2) | 10.6913 | 9.7816 | 9.8166 | 9.9089 | 9.6774 | 174 |
| sample 3 (partial conversion 1) | 10.8754 | 10.1588 | 10.2488 | 10.325 | 10.109 | 199 |
| sample 4 (partial conversion 2) | 10.2786 | 9.6152 | 9.7069 | 9.7771 | 9.5636 | 200 |

* each block corresponds to 32 scans

**Table S7**.

| **sample name (standard deviation)** | **C1** | **C2** | **C3** | **C4** | **C5** |
|---|---|---|---|---|---|
| sample 1 (full conversion 1) | 0.2473 | 0.2308 | 0.2364 | 0.2253 | 0.2206 |
| sample 2 (full conversion 2) | 0.2600 | 0.2205 | 0.2349 | 0.2363 | 0.2330 |
| sample 3 (partial conversion 1) | 0.2532 | 0.2168 | 0.2492 | 0.2201 | 0.2603 |
| sample 4 (partial conversion 2) | 0.2710 | 0.2208 | 0.2013 | 0.2073 | 0.2002 |

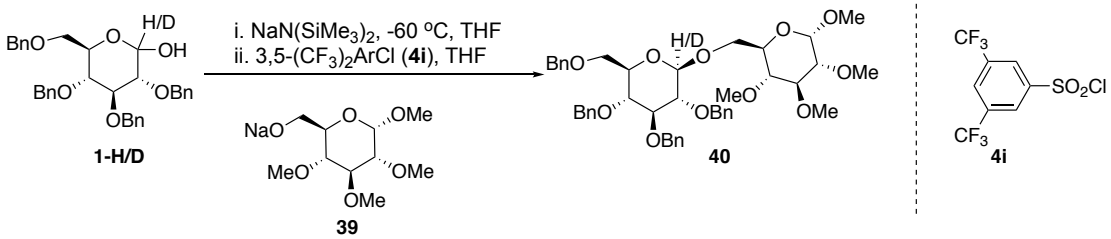
**Table S8**.

| ratios ($^{13}C/^{12}C$) | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| sample 1 (full conversion 1) | 1.0919 | 0.9933 | 1.0000 | 1.0079 | 0.9817 |
| sample 2 (full conversion 2) | 1.0891 | 0.9964 | 1.0000 | 1.0094 | 0.9858 |
| sample 3 (partial conversion 1) | 1.0611 | 0.9912 | 1.0000 | 1.0074 | 0.9864 |
| sample 4 (partial conversion 2) | 1.0589 | 0.9906 | 1.0000 | 1.0072 | 0.9852 |

**Table S9**.

| experimental KIEs | C1 | C2 | C4 | C5 |
|---|---|---|---|---|
| measurement 1 | 1.032(4) | 1.004(4) | 1.001(4) | 0.997(4) |
| measurement 2 | 1.035(4) | 1.005(4) | 1.002(4) | 0.998(4) |

## 5.2 α-SDKIE measurements




To gain further insight into the mechanism of the glycosylation reactions, secondary H/D KIE measurements were conducted. The KIE was calculated according to:

$KIE = \ln(1-F)/\ln[1-(FR_p/R_0)]$

where F is the fractional conversion of the α-sulfonate (yield of **40**), $R_0$ is the ratio of heavy to light isotopologues in starting material, and $R_p$ is the ratio of heavy to light isotopologues in product. The quantity of heavy isotopologue was calculated by subtracting the NMR integral of the anomeric peak from that of a reference peak. (Two reference peaks were considered and their integrals were found to be within 0.5% of one another. The average of the two reference integrals was taken as the overall reference.)

R = [heavy]/[light]

R= [(integral of reference 1+ integral of reference 2)/2- integral of anomeric peak]/ integral of anomeric peak

Three independent α-SDKIE measurements were made. For each of the three pairs of spectra, $R_0$ was determined by integrating the spectrum of the full conversion sample,

while $R_p$ was determined by integrating the spectrum of the partial conversion sample. This method ensures minimizes errors, since the same peaks and integration ranges are used for all measurements. To further improve consistency, the NMR samples were prepared with the same concentration.

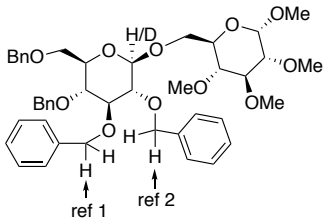
The NMR spectra were recorded on a Bruker Avance III NMR spectrometer at 500 MHz for $^1$H NMR. The relaxation delay was set to 60 s. Each $^1$H spectrum was acquired with a 5.5 ppm sweep width and 4 scans. The NMR data was processed using MestReNova version 6.1. The baseline was corrected to remove the baseline distortions that are associated with $^1$H NMR using the Whittaker Smoother method found in MestReNova.

**Partial conversion:**

Donor **1**-H/D (prepared by mixing an approximately equal quantity of the nondeuterated material to deuterated material; total 0.2161 g, 0.4 mmol) was dissolved in 2.0 mL of THF. A portion (0.2 mL) of this solution was used for the full conversion reaction. The remaining donor solution was cooled to –60 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.36 mL, 0.36 mmol). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.1123 g, 0.36 mmol, 4 equiv.) in 1.8 mL of THF that had been pre-cooled to –60 °C. The flask that contained the donor was rinsed with an additional 0.9 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this mixture has stirred for two hours at –60 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **39** (0.0213 g, 0.09 mmol, 1 equiv.) in 0.5 mL of THF at –60 °C with sodium hexamethyldisilazane (0.09 mL, 0.09 mmol, 1 equiv.) and stirring for 10 minutes). The flask that contained the acceptor was rinsed with 0.5 mL of THF, and this rinse was then added to the glycosylation reaction. After 2 hours, the reaction was quenched with 0.1 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 15 mL). The combined organic phase was washed with brine (30 mL) and then dried ($Na_2SO_4$). The internal standard 1-bromo-2,4,6-tri-*tert*-butylbenzene (0.09 mmol) was added to the solution containing the crude sample. An aliquot (1.0 mL) of this solution was removed for NMR analysis. The remaining solution was concentrated, and the crude product was purified by silica gel flash column chromatography (30% ethyl acetate in hexane) to afford disaccharide **40** exclusively as the β-isomer. $R_p$ was measured by $^1$H NMR (15.8 mM of disaccharide **40** in $CD_2Cl_2$, ns = 4, d1 = 60 s).

**Full conversion:**

The portion (0.2 mL) of the above donor solution was cooled to –60 °C and treated with sodium hexamethyldisilazane (1 M in THF, 0.04 mL, 0.04 mmol). After 10 minutes, this solution was transferred by syringe to a flask containing the solution of 3,5-bis(trifluoromethyl)benzenesulfonyl chloride **4i** (0.0125 g, 0.04 mmol, 1 equiv.) in 0.2 mL of THF that had been pre-cooled to –60 °C. The flask that contained the donor was rinsed with an additional 0.2 mL of THF, and this rinse was then added to the donor and sulfonyl chloride reaction mixture. After this reaction mixture has stirred for two hours at –60 °C, it was treated with a freshly prepared solution of the alkoxide acceptor (prepared by treating a solution of acceptor **39** (0.0378 g, 0.16 mmol, 4 equiv.) in 0.8 mL of THF at –60 °C with sodium hexamethyldisilazane (0.16 mL, 0.16 mmol, 4 equiv.) and stirring for 10 minutes.). The flask that contained the acceptor was rinsed with 0.4 mL of THF, and this rinse was then added to the glycosylation reaction. After 6 hours, the reaction was quenched with 0.01 mL of saturated aqueous ammonium chloride ($NH_4Cl$), diluted with water, and extracted with diethyl ether (4 x 5 mL). The combined organic phase was washed with brine (10 mL) and then dried ($Na_2SO_4$). An internal standard 1-bromo-2,4,6-tri-*tert*-butylbenzene (0.04 mmol) was added to the solution containing the crude sample. An aliquot of 1.0 mL was removed for NMR analysis. The rest of the solution was concentrated, and the crude product was purified by silica gel flash column chromatography (30% ethyl acetate in hexane) to afford disaccharide **40** exclusively as the β-isomer. $R_0$ was measured by $^1$H NMR (15.8 mM of disaccharide **40** in $CD_2Cl_2$, ns = 4, d1 = 60s).




structure of **40**

Reference peak 1 (ref 1):

The region from 4.954 ppm to 4.897 ppm in the $^1$H NMR spectrum ($CD_2Cl_2$) was taken as reference peak 1. This peak corresponds to one of the diastereotopic methylene protons of the benzyl group attached to the C3 position of the donor in product **40**.

Reference peak 2 (ref 2):

The region from 5.074 ppm to 4.988 ppm in the $^1$H NMR spectrum ($CD_2Cl_2$) was taken as reference peak 2. This peak corresponds to one of the diastereotopic methylene protons of the benzyl group attached to the C2 position of the donor in product **40**.

Anomeric peak:

The region from 4.519 ppm to 4.468 ppm in the $^1$H NMR spectrum ($CD_2Cl_2$) was taken as the anomeric peak.

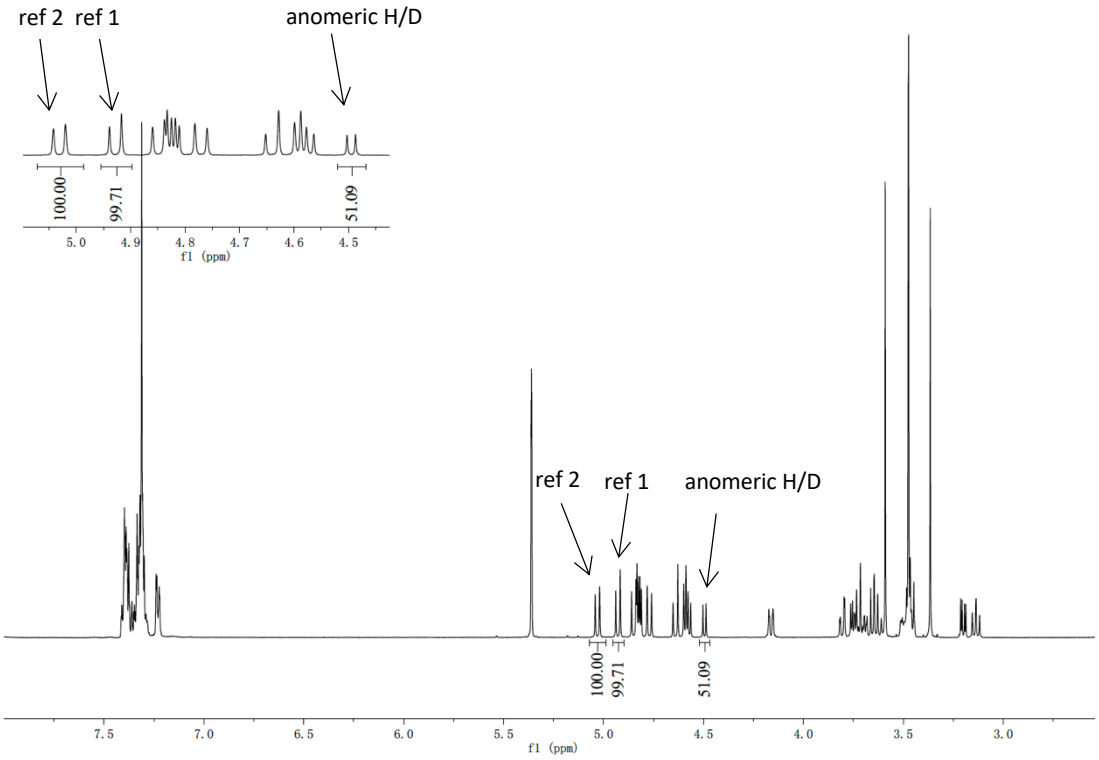
**Table S10.** NMR integral and calculation of $R_0$ and $R_p$ for α-SKIE

| | full conversion | | | | partial conversion | | | |
|---|---|---|---|---|---|---|---|---|
| run | integral of anomeric peak | integral of ref 1 | integral of ref 2 | $R_0$ | integral of anomeric peak | integral of ref 1 | integral of ref 2 | $R_p$ |
| integration range (ppm) | 4.519-4.468 | 4.954-4.897 | 5.074-4.988 | | 4.519-4.468 | 4.954-4.897 | 5.074-4.988 | |
| 1 | 51.09 | 99.71 | 100.00 | 0.9545 | 54.52 | 99.80 | 100.00 | 0.8324 |
| 2 | 51.39 | 99.65 | 100.00 | 0.9425 | 54.61 | 99.97 | 100.00 | 0.8309 |
| 3 | 52.14 | 99.60 | 100.00 | 0.9141 | 55.56 | 100.26 | 100.00 | 0.8022 |

**Table S11.** Summary of α-SKIE

| run | F | ln(1-F) | $R_0$ | $R_p$ | ln[1-(F$R_p$/$R_0$)] | α-SDKIE |
|---|---|---|---|---|---|---|
| 1 | 0.235 | -0.2679 | 0.9545 | 0.8324 | -0.2293 | 1.17 |
| 2 | 0.235 | -0.2679 | 0.9425 | 0.8309 | -0.2322 | 1.15 |
| 3 | 0.245 | -0.2810 | 0.9140 | 0.8022 | -0.2421 | 1.16 |
| average | | | | | | 1.16 |

**full conversion** (product **40** $^{1}$H NMR in $CD_2Cl_2$, 500 MHz)




**partial conversion** (product **40** $^{1}$H NMR in $CD_2Cl_2$, 500 MHz)

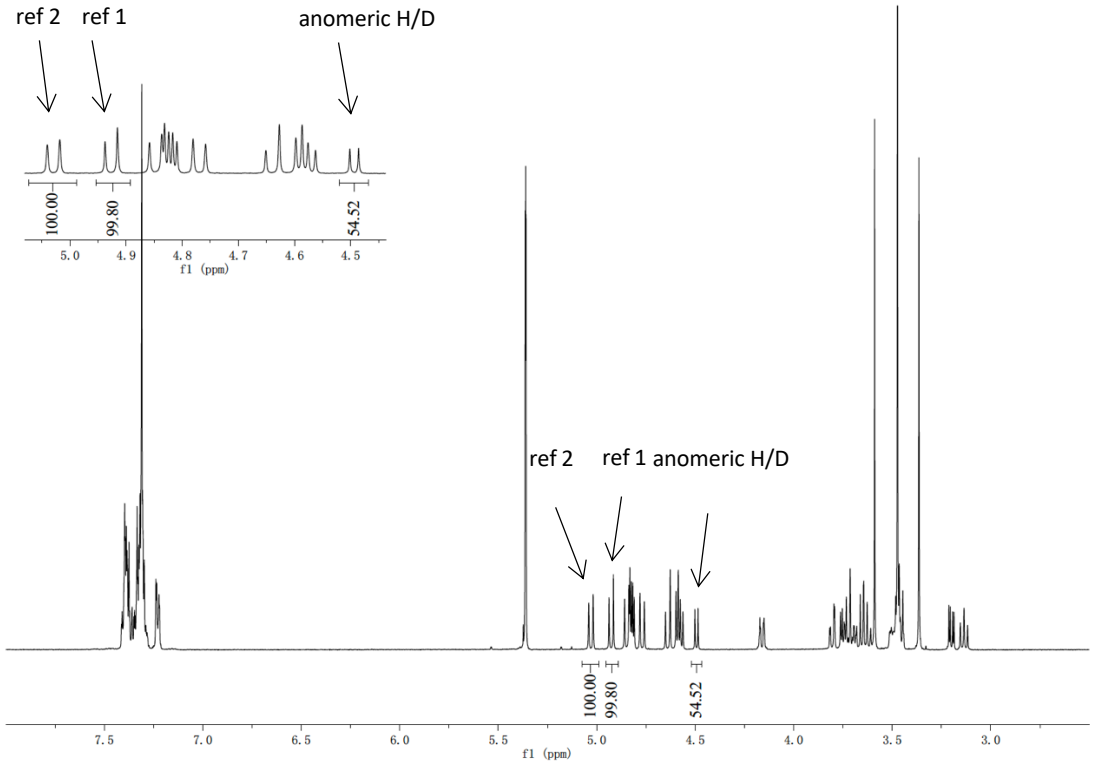
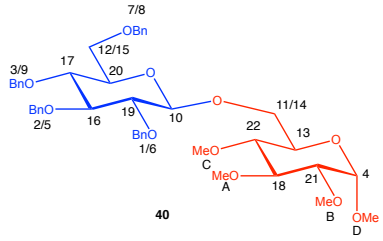



**Figure S4.** One set of $^{1}$H NMR spectra of product **40** (one full conversion sample and one partial conversion sample).

## 5.3 Detailed characterization of disaccharide 40




Spectra were taken by 20 mg of disaccharide **40** in $CDCl_3$. Aryl peaks are not given. (Donor on left and acceptor on right)

**Table S12.** Characterization of disaccharide **40**

| # | $^{1}$H (ppm) | $^{13}$C (ppm) | Notes ($^{1}J_{CH}$) |
|---|---|---|---|
| 1 | 5.01 | 74.87 | |
| 2 | 4.91 | 75.72 | |
| 3 | 4.82 | 75.02 | |
| 4 | 4.81 | 97.35 | acceptor anomeric (170 Hz) |
| 5 | 4.78 | 75.72 | |
| 6 | 4.75 | 74.87 | |
| 7 | 4.59 | 73.44 | |
| 8 | 4.59 | 73.44 | |
| 9 | 4.55 | 75.02 | |
| 10 | 4.47 | 103.90 | donor anomeric (159 Hz) |
| 11 | 4.19 | 68.83 | |
| 12 | 3.76 | 69.08 | donor C6 (142 Hz) |
| 13 | 3.72 | 69.85 | |
| 14 | 3.71 | 68.83 | |
| 15 | 3.70 | 69.08 | donor C6 (142 Hz) |
| 16 | 3.66 | 84.83 | donor C3 (140 Hz) |
| 17 | 3.58 | 77.97 | donor C4 (145 Hz) |
| 18 | 3.52 | 83.48 | |
| 19 | 3.51 | 82.19 | donor C2 (144 Hz) |
| 20 | 3.50 | 75.09 | donor C5 (137 Hz) |
| 21 | 3.20 | 81.80 | |
| 22 | 3.13 | 79.83 | |
| A | 3.62 | 60.81 | |
| B | 3.50 | 60.40 | |
| C | 3.47 | 58.94 | |
| D | 3.36 | 55.18 | |

## 6. DFT Calculation Procedures and Data

### 6.1. General procedures

DFT calculations were carried out using *Gaussian 16, Revision A.03*:

M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, G. A. Petersson, H. Nakatsuji, X. Li, M. Caricato, A. V. Marenich, J. Bloino, B. G. Janesko, R. Gomperts, B. Mennucci, H. P. Hratchian, J. V. Ortiz, A. F. Izmaylov, J. L. Sonnenberg, D. Williams-Young, F. Ding, F. Lipparini, F. Egidi, J. Goings, B. Peng, A. Petrone, T. Henderson, D. Ranasinghe, V. G. Zakrzewski, J. Gao, N. Rega, G. Zheng, W. Liang, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, K. Throssell, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. J. Bearpark, J. J. Heyd, E. N. Brothers, K. N. Kudin, V. N. Staroverov, T. A. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. P. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, J. M. Millam, M. Klene, C. Adamo, R. Cammi, J. W. Ochterski, R. L. Martin, K. Morokuma, O. Farkas, J. B. Foresman, and D. J. Fox, Gaussian, Inc., Wallingford CT, 2016.

All stationary points were verified to be true local minima or first-order saddle points by frequency analysis (298.15 K). The default Gaussian standard state was used.

Kinetic isotope effects were predicted using PyQuiver (www.github.com/ekwan/PyQuiver). 3D renderings were made with CYLview. Graphs and statistical analyses were generated in Python using numpy and matplotlib. Conformational searching was performed with Macromodel.

All key Gaussian output files have been deposited at https://github.com/ekwan/bennett_glycosylation, along with the PyQuiver configuration files that are necessary to reproduce the findings discussed below.

A .zip file containing the $S_N2$ transition structures has been included separately. Files are in plain-text Gaussian input file format. The electronic energy, free energy, and number of imaginary frequencies are included in the title card.

### 6.2. Prediction of $S_N1$ isotope effects

We assumed that the transition state for an $S_N1$ reaction resembles its carbocation and estimated equilibrium isotope effects (EIEs) by comparing the aryl sulfonate to its corresponding cation. The predicted EIEs are essentially insensitive to the choice of DFT method.[25] Therefore, B3LYP-D3(BJ)/6-31G*/PCM(THF) was chosen as a "standard" method. However, the predicted EIEs are somewhat sensitive to conformation, as the bond lengths of the cation (and therefore the vibrational energies

of the cation) depend on the degree to which adjacent bonds are aligned for hyperconjugation. Several hundred candidate conformations for both per-methyl glucose 3,5-bis(trifluoromethyl)sulfonate and per-methyl glucose cation were generated using molecular mechanics (Macromodel, OPLS_2005 force field, gas phase). Each structure was then re-minimized using the above DFT method. The lowest-energy glucose sulfonate conformation was chosen as the ground state reference for all subsequent calculations.

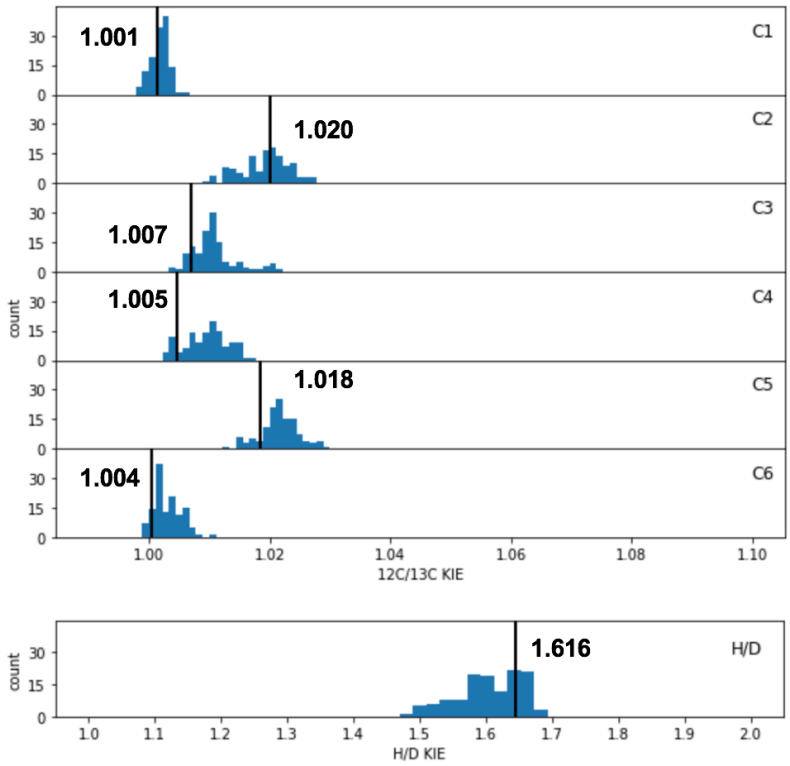



**Figure S5.** Distribution of predicted EIEs for an $S_N1$ process (213 K, unscaled frequencies). Black bars and numbers indicate the predicted values for the lowest-energy glucose cation.

We then considered the predicted EIEs for an $S_N1$ process. The EIE at C1 is near unity. This reflects a near-perfect cancellation of two opposing effects: leaving-group bond heterolysis (normal effect) and hyperconjugative stabilization of the carbocation by all adjacent bonds (inverse effect). This latter hyperconjugative effect is manifested in the significant normal KIEs at C2 and C5, as well as the smaller effects at more remote centers.

The secondary hydrogen/deuterium EIE largely reflects the relative stiffness of the out-of-plane mode between the ground state and the cation. The predicted EIEs range from 1.5–1.7 with a value of 1.62 for the lowest-energy conformation of the cation. This is a relatively large secondary EIE that is consistent with the transition from $sp^3$ to $sp^2$ bonding at C1. More realistic models of the $S_N1$ process would include the leaving group (and possibly the nucleophile). These groups would restrict the motion of C1, stiffening the out-of-plane mode in the transition state, and therefore

reduce the expected isotope effect. The experimental isotope effect is far less than the predicted range of values for an $S_N1$ process, providing evidence against an oxocarbenium ion.

### 6.3. Prediction of $S_N2$ isotope effects

The relatively large normal KIE experimentally observed at C1 suggests that the reaction is proceeding through an $S_N2$ pathway. Therefore, detailed computational models of many possible $S_N2$ transition states were constructed and their predicted KIEs compared to experiment. Once again, B3LYP-D3(BJ)/6-31G* was employed as a standard method. This method has previously been demonstrated[26] to reproduce experimental KIEs for traditional $S_N2$ reactions. Solvation was found to be extremely important. A hybrid implicit/explicit solvation model was used in which an explicit sodium counterion for the alkoxide was included, along with one explicit dimethyl ether ligand. The rest of the solvent was represented implicitly with PCM (THF).

There are many possible degrees of freedom in the coupling between two glucose molecules. To reduce the size of the system, all protecting groups were truncated to methyl. (Experimentally, the reaction was performed with methyl protecting groups on the acceptor and benzyl protecting groups on the donor. Performing the reaction with methyl protecting groups on both partners resulted in a reaction with reduced yield but high stereoselectivity.)

We developed a systematic nomenclature scheme so that we could extensively explore the remaining degrees of freedom. The conformations of the donor and acceptor were taken from the lowest six conformations found for the glucose 3,5-bis(trifluoromethyl)sulfonate and labeled A–F. The orientation of the acceptor relative to the donor was designated as "up" (U) or "down" (D). The orientation of the aryl group of the arylsulfonate was designated as "left" (L) or "right" (R). This led to a four-character system for labeling candidate transition structures. For example, AAUL indicates that both the donor and acceptor were in the lowest-energy ground state conformation, with the acceptor in the "up" orientation and the leaving group in the "left" orientation. (A few configurations from exploratory work were designated as "original" using the abbreviations ORG1, ORG2, etc.) In some cases, the conformation drifted away from the original labeling during the transition state search. In all cases, the transition state label reflects the original label only.

After a comprehensive search, a total of 106 distinct transition states were found, spanning a range of 34 kcal/mol in electronic energy:

| conformer | type | energy | forming | breaking | angle | imaginary |
|---|---|---|---|---|---|---|
| FAUR | a | 0.0000 | 2.387 | 1.928 | 160.372 | 356 |
| CDUR | a | 1.7875 | 2.373 | 1.940 | 108.144 | 378 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CDDR | a | 2.3228 | 2.426 | 1.948 | 162.949 | 336 |
| ADDR | a | 2.3811 | 2.398 | 1.963 | 161.803 | 334 |
| BCDR | b | 2.4169 | 2.487 | 2.162 | 138.258 | 155 |
| CADR | a | 2.8816 | 2.462 | 2.049 | 157.238 | 255 |
| BCUR | b | 3.2180 | 2.562 | 2.137 | 134.684 | 113 |
| EADR | b | 3.2608 | 2.500 | 2.182 | 134.646 | 138 |
| CADR | b | 3.3074 | 2.573 | 2.118 | 135.133 | 119 |
| BCDL | b | 3.5756 | 2.566 | 2.121 | 137.184 | 120 |
| CCUL | b | 3.6488 | 2.572 | 2.136 | 138.398 | 126 |
| CCDL | b | 3.6964 | 2.552 | 2.131 | 136.845 | 130 |
| ECDR | b | 4.6517 | 2.461 | 2.309 | 130.274 | 142 |
| AAUL | a | 4.7652 | 2.376 | 1.975 | 163.002 | 352 |
| AADL | a | 4.7915 | 2.486 | 2.008 | 165.005 | 222 |
| AADL | b | 5.1097 | 2.486 | 2.341 | 122.858 | 87 |
| FAUR | b | 5.2527 | 2.429 | 2.355 | 132.056 | 129 |
| ECUL | b | 5.2927 | 2.538 | 2.120 | 135.039 | 129 |
| CCUL | a | 5.3567 | 2.388 | 1.945 | 163.255 | 338 |
| EDDR | a | 5.4600 | 2.403 | 1.922 | 164.772 | 351 |
| CCDL | a | 5.5779 | 2.459 | 2.034 | 163.988 | 232 |
| DADL | b | 5.5867 | 2.469 | 2.179 | 132.186 | 155 |
| ACDR | b | 5.9670 | 2.593 | 2.291 | 119.900 | 114 |
| FCDL | b | 6.0082 | 2.584 | 2.124 | 138.872 | 127 |
| EADL | b | 6.2948 | 2.513 | 2.243 | 122.770 | 99 |
| DCDR | b | 6.6099 | 2.513 | 2.377 | 116.013 | 109 |
| BDDL | a | 6.8750 | 2.398 | 1.944 | 162.230 | 334 |
| DCUR | b | 6.9934 | 2.646 | 2.018 | 132.206 | 111 |
| ACDL | a | 7.0170 | 2.468 | 1.990 | 164.277 | 248 |
| DCDL | b | 7.0430 | 2.546 | 2.183 | 129.313 | 97 |
| FADL | b | 7.2585 | 2.471 | 2.296 | 135.930 | 133 |
| CADL | a | 7.4560 | 2.453 | 1.986 | 164.854 | 251 |
| EAUL | a | 7.7936 | 2.360 | 1.948 | 161.075 | 365 |
| CCDR | b | 8.4397 | 2.589 | 2.152 | 138.821 | 99 |
| BDUL | a | 8.4498 | 2.468 | 1.927 | 147.610 | 296 |
| CADL | b | 8.5692 | 2.532 | 2.218 | 125.902 | 108 |
| FDUL | b | 8.9756 | 2.557 | 2.251 | 135.189 | 112 |
| BAUL | a | 9.3937 | 2.572 | 1.972 | 154.283 | 195 |
| EADL | a | 9.4944 | 2.473 | 1.951 | 163.967 | 271 |
| AADR | b | 9.6888 | 2.428 | 2.309 | 128.486 | 148 |
| FDDR | a | 9.8211 | 2.491 | 1.987 | 152.142 | 239 |
| FCDR | b | 10.3586 | 2.549 | 2.181 | 139.845 | 105 |
| DDDL | b | 10.3754 | 2.553 | 2.045 | 135.034 | 144 |
| DDUR | b | 10.4764 | 2.509 | 2.230 | 127.886 | 141 |
| ADUL | b | 10.6903 | 2.620 | 2.145 | 132.481 | 160 |
| EAUR | b | 10.8866 | 2.532 | 2.193 | 74.747 | 138 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CAUR | b | 11.0411 | 2.603 | 2.191 | 129.432 | 152 |
| AAUR | b | 11.1019 | 2.463 | 2.167 | 133.207 | 215 |
| BCUL | a | 11.2037 | 2.566 | 1.930 | 151.347 | 249 |
| AAUL | a | 11.3519 | 2.353 | 1.960 | 146.406 | 363 |
| DDDR | a | 11.5284 | 2.413 | 1.981 | 160.300 | 312 |
| BDUL | b | 11.9100 | 2.611 | 2.178 | 129.549 | 86 |
| ADDL | b | 11.9492 | 2.587 | 2.272 | 124.322 | 194 |
| DCUL | b | 12.0487 | 2.611 | 2.139 | 130.964 | 159 |
| EDDR | b | 12.0557 | 2.674 | 2.223 | 124.882 | 66 |
| FCUR | b | 12.3964 | 2.437 | 2.213 | 131.863 | 152 |
| BDDL | a | 12.6640 | 2.398 | 1.978 | 147.583 | 349 |
| ECDL | b | 12.9602 | 2.621 | 2.064 | 135.562 | 167 |
| EDDL | a | 13.1272 | 2.530 | 1.911 | 150.383 | 277 |
| CDUR | b | 13.2539 | 2.468 | 2.197 | 136.650 | 199 |
| ADUL | a | 13.2642 | 2.543 | 1.928 | 156.631 | 228 |
| DADR | b | 13.6975 | 2.574 | 2.276 | 128.596 | 160 |
| ADUR | a | 13.8669 | 2.490 | 1.960 | 156.777 | 228 |
| FAUL | b | 14.4052 | 2.619 | 2.230 | 125.276 | 105 |
| CADL | c | 14.5679 | 2.702 | 1.908 | 114.531 | 111 |
| FADL | a | 14.9101 | 2.493 | 2.029 | 163.522 | 207 |
| EDDL | b | 14.9368 | 2.482 | 2.208 | 129.700 | 229 |
| DCUR | a | 15.1039 | 2.557 | 2.001 | 148.644 | 212 |
| BDDL | b | 15.1777 | 2.470 | 2.357 | 127.840 | 119 |
| DADL | a | 15.2131 | 2.822 | 1.911 | 138.161 | 115 |
| DAUR | b | 15.2751 | 2.535 | 2.174 | 135.896 | 190 |
| DCDL | a | 16.0037 | 2.509 | 2.031 | 163.652 | 205 |
| ECDL | a | 16.0795 | 2.499 | 1.999 | 162.591 | 194 |
| ORG2 | a | 16.1409 | 2.626 | 2.010 | 153.694 | 211 |
| ADDR | b | 16.4420 | 2.430 | 1.975 | 149.100 | 320 |
| CCDR | c | 16.4478 | 2.695 | 1.817 | 134.083 | 272 |
| BCUR | c | 16.9232 | 2.751 | 1.781 | 149.145 | 272 |
| BCUL | c | 17.6896 | 2.623 | 1.825 | 151.025 | 339 |
| DCDL | c | 17.7963 | 2.604 | 1.765 | 164.215 | 337 |
| ECUL | c | 17.8996 | 2.479 | 2.761 | 92.161 | 138 |
| DDUL | a | 17.9494 | 2.627 | 1.868 | 159.366 | 306 |
| DDDR | b | 18.2475 | 2.523 | 2.283 | 125.952 | 70 |
| FCDR | c | 18.7734 | 2.613 | 1.844 | 147.192 | 340 |
| EDDL | b | 19.3966 | 2.426 | 2.307 | 133.981 | 126 |
| DDUR | a | 20.6249 | 2.631 | 1.895 | 148.945 | 216 |
| BAUR | c | 21.4003 | 2.687 | 1.831 | 140.620 | 291 |
| FCUL | a | 22.2016 | 2.643 | 1.919 | 145.955 | 214 |
| DDUL | b | 22.3042 | 2.637 | 1.845 | 139.746 | 290 |
| CAUL | c | 22.3472 | 2.741 | 1.737 | 131.388 | 142 |
| FCUL | c | 22.6774 | 2.466 | 1.769 | 157.986 | 409 |

| | | | | | | |
|---|---|---|---|---|---|---|
| BCDR | c | 22.6842 | 2.665 | 1.786 | 172.981 | 329 |
| FADL | c | 22.7471 | 2.601 | 1.760 | 150.465 | 311 |
| BDUR | c | 22.9521 | 2.596 | 1.961 | 142.747 | 142 |
| DADL | c | 23.2194 | 2.621 | 1.829 | 126.545 | 263 |
| CDDL | c | 23.4025 | 2.693 | 1.709 | 167.232 | 217 |
| DAUR | c | 23.6939 | 2.657 | 1.860 | 132.288 | 287 |
| EDUL | c | 24.4791 | 2.512 | 1.848 | 146.326 | 382 |
| CCUL | c | 25.0791 | 2.662 | 1.791 | 150.799 | 296 |
| CCDL | c | 25.8784 | 2.693 | 1.786 | 151.963 | 284 |
| BCDL | c | 25.9315 | 2.752 | 1.746 | 155.896 | 272 |
| DCUL | c | 28.5948 | 2.704 | 1.810 | 119.139 | 231 |
| AADL | c | 31.0292 | 2.657 | 1.932 | 126.166 | 122 |
| CDDR | c | 31.7619 | 2.720 | 1.750 | 136.283 | 206 |
| AAUR | c | 32.4446 | 2.681 | 1.863 | 158.016 | 283 |
| DDDR | c | 33.8933 | 2.587 | 1.707 | 162.901 | 316 |
| AAUL | c | 33.8940 | 2.668 | 1.828 | 169.793 | 369 |

Legend:
Conformer = donor/acceptor conformation
Type = solvation sphere geometry (a=sodium bound to alkoxide, b = bridging sodium, c = sodium bound to sulfonate)
Energy = electronic energy in kcal/mol
Forming and breaking = bond distances in Å
Angle = nucleophile-carbon-leaving-group angle, and imaginary refers to the curvature of the reaction coordinate in $cm^{-1}$. The highlighted structure (BCDR, type b) near the top was the lowest in energy and is described in the main text.

The calculated KIEs were:

| conformer | type | C1 | C2 | C3 | C4 | C5 | C6 | HD |
|---|---|---|---|---|---|---|---|---|
| FAUR | a | 1.0821 | 1.0039 | 1.0007 | 1.0013 | 1.0008 | 1.0004 | 1.1882 |
| CDUR | a | 1.0836 | 1.0041 | 1.0003 | 1.0001 | 0.9988 | 0.9982 | 1.1064 |
| CDDR | a | 1.0756 | 1.0042 | 1.0011 | 1.0019 | 0.9995 | 0.9991 | 1.1955 |
| ADDR | a | 1.0759 | 1.0046 | 1.0014 | 1.0003 | 0.9984 | 0.9984 | 1.2136 |
| BCDR | b | 1.0362 | 1.0072 | 1.0023 | 1.0018 | 1.0056 | 0.9981 | 1.2991 |
| CADR | a | 1.0651 | 1.0072 | 1.0007 | 1.0012 | 1.0014 | 0.9988 | 1.2761 |
| BCUR | b | 1.0297 | 1.0060 | 1.0014 | 1.0024 | 1.0058 | 0.9987 | 1.3928 |
| EADR | b | 1.0306 | 1.0075 | 1.0020 | 1.0039 | 1.0099 | 1.0008 | 1.4268 |
| CADR | b | 1.0316 | 1.0058 | 1.0013 | 1.0022 | 1.0059 | 0.9985 | 1.3998 |
| BCDL | b | 1.0318 | 1.0057 | 1.0008 | 1.0022 | 1.0062 | 0.9985 | 1.3637 |
| CCUL | b | 1.0333 | 1.0062 | 1.0013 | 1.0018 | 1.0060 | 0.9985 | 1.3588 |
| CCDL | b | 1.0338 | 1.0049 | 1.0008 | 1.0021 | 1.0061 | 0.9985 | 1.3214 |
| ECDR | b | 1.0288 | 1.0122 | 1.0026 | 1.0025 | 1.0051 | 0.9994 | 1.3205 |
| AAUL | a | 1.0790 | 1.0041 | 1.0000 | 1.0011 | 1.0002 | 0.9989 | 1.1840 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AADL | a | 1.0634 | 1.0046 | 1.0002 | 1.0013 | 1.0007 | 0.9990 | 1.1943 |
| AADL | b | 1.0187 | 1.0080 | 1.0019 | 1.0024 | 1.0062 | 0.9986 | 1.4929 |
| FAUR | b | 1.0285 | 1.0067 | 1.0007 | 1.0026 | 1.0080 | 0.9999 | 1.4067 |
| ECUL | b | 1.0315 | 1.0059 | 1.0020 | 1.0040 | 1.0093 | 1.0013 | 1.4113 |
| CCUL | a | 1.0811 | 1.0029 | 0.9996 | 1.0009 | 1.0004 | 0.9989 | 1.2133 |
| EDDR | a | 1.0771 | 1.0032 | 1.0014 | 1.0023 | 1.0042 | 1.0022 | 1.2128 |
| CCDL | a | 1.0648 | 1.0058 | 1.0002 | 1.0006 | 1.0014 | 0.9990 | 1.2106 |
| DADL | b | 1.0328 | 1.0064 | 1.0014 | 1.0049 | 1.0116 | 1.0012 | 1.4621 |
| ACDR | b | 1.0170 | 1.0103 | 1.0063 | 1.0078 | 1.0072 | 0.9996 | 1.6830 |
| FCDL | b | 1.0350 | 1.0055 | 1.0008 | 1.0029 | 1.0066 | 0.9995 | 1.3349 |
| EADL | b | 1.0205 | 1.0072 | 1.0027 | 1.0044 | 1.0115 | 1.0020 | 1.5152 |
| DCDR | b | 1.0164 | 1.0125 | 1.0094 | 1.0082 | 1.0091 | 1.0042 | 1.7543 |
| BDDL | a | 1.0790 | 1.0032 | 0.9996 | 1.0008 | 0.9999 | 0.9987 | 1.2073 |
| DCUR | b | 1.0301 | 1.0040 | 1.0014 | 1.0031 | 1.0122 | 1.0030 | 1.3763 |
| ACDL | a | 1.0691 | 1.0060 | 0.9998 | 1.0006 | 1.0007 | 0.9990 | 1.2038 |
| DCDL | b | 1.0265 | 1.0059 | 1.0008 | 1.0045 | 1.0136 | 1.0030 | 1.4827 |
| FADL | b | 1.0303 | 1.0075 | 1.0010 | 1.0023 | 1.0081 | 1.0005 | 1.4510 |
| CADL | a | 1.0701 | 1.0057 | 0.9998 | 1.0007 | 1.0002 | 0.9988 | 1.1977 |
| EAUL | a | 1.0792 | 1.0043 | 1.0011 | 1.0024 | 1.0021 | 1.0019 | 1.1480 |
| CCDR | b | 1.0308 | 1.0060 | 1.0013 | 1.0019 | 1.0066 | 0.9985 | 1.2926 |
| BDUL | a | 1.0744 | 1.0041 | 1.0002 | 1.0005 | 1.0012 | 0.9988 | 1.2784 |
| CADL | b | 1.0237 | 1.0104 | 1.0069 | 1.0084 | 1.0059 | 0.9998 | 1.3707 |
| FDUL | b | 1.0269 | 1.0069 | 1.0018 | 1.0032 | 1.0069 | 1.0001 | 1.3685 |
| BAUL | a | 1.0593 | 1.0041 | 0.9996 | 1.0004 | 1.0022 | 0.9993 | 1.2867 |
| EADL | a | 1.0711 | 1.0052 | 1.0008 | 1.0007 | 1.0039 | 1.0034 | 1.1722 |
| AADR | b | 1.0300 | 1.0120 | 1.0007 | 1.0004 | 1.0074 | 0.9988 | 1.3577 |
| FDDR | a | 1.0643 | 1.0041 | 1.0002 | 1.0010 | 1.0012 | 0.9982 | 1.2539 |
| FCDR | b | 1.0324 | 1.0069 | 1.0020 | 1.0029 | 1.0058 | 0.9997 | 1.2806 |
| DDDL | b | 1.0380 | 1.0050 | 1.0007 | 1.0041 | 1.0113 | 1.0020 | 1.4041 |
| DDUR | b | 1.0267 | 1.0054 | 1.0014 | 1.0054 | 1.0124 | 1.0013 | 1.5007 |
| ADUL | b | 1.0274 | 1.0073 | 1.0027 | 1.0013 | 1.0095 | 1.0007 | 1.4267 |
| EAUR | b | 1.0269 | 1.0093 | 1.0029 | 1.0041 | 1.0097 | 1.0014 | 1.3099 |
| CAUR | b | 1.0214 | 1.0054 | 1.0015 | 0.9997 | 1.0051 | 0.9988 | 1.3850 |
| AAUR | b | 1.0420 | 1.0112 | 1.0013 | 0.9998 | 1.0033 | 0.9968 | 1.3019 |
| BCUL | a | 1.0683 | 1.0048 | 0.9998 | 1.0018 | 1.0000 | 0.9984 | 1.2707 |
| AAUL | a | 1.0849 | 1.0038 | 1.0007 | 1.0002 | 0.9995 | 0.9989 | 1.2000 |
| DDDR | a | 1.0717 | 1.0036 | 1.0000 | 1.0025 | 1.0064 | 0.9998 | 1.2492 |
| BDUL | b | 1.0227 | 1.0060 | 1.0013 | 1.0020 | 1.0057 | 0.9994 | 1.5015 |
| ADDL | b | 1.0174 | 1.0109 | 1.0032 | 1.0040 | 1.0080 | 0.9993 | 1.7364 |
| DCUL | b | 1.0271 | 1.0060 | 1.0010 | 1.0029 | 1.0121 | 1.0023 | 1.4148 |
| EDDR | b | 1.0193 | 1.0059 | 1.0013 | 1.0031 | 1.0107 | 1.0024 | 1.4533 |
| FCUR | b | 1.0354 | 1.0098 | 1.0015 | 1.0033 | 1.0114 | 1.0021 | 1.2570 |
| BDDL | a | 1.0708 | 1.0050 | 1.0007 | 1.0006 | 1.0021 | 0.9975 | 1.1000 |
| ECDL | b | 1.0315 | 1.0053 | 1.0016 | 1.0025 | 1.0070 | 1.0005 | 1.3039 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EDDL | a | 1.0681 | 1.0048 | 1.0001 | 1.0036 | 1.0040 | 1.0016 | 1.2202 |
| CDUR | b | 1.0384 | 1.0107 | 1.0007 | 0.9992 | 1.0028 | 0.9983 | 1.3813 |
| ADUL | a | 1.0608 | 1.0036 | 0.9993 | 1.0006 | 1.0049 | 1.0004 | 1.1763 |
| DADR | b | 1.0244 | 1.0112 | 1.0014 | 1.0036 | 1.0117 | 1.0023 | 1.4469 |
| ADUR | a | 1.0597 | 1.0032 | 0.9996 | 1.0007 | 1.0047 | 1.0005 | 1.1726 |
| FAUL | b | 1.0228 | 1.0115 | 1.0069 | 1.0071 | 1.0063 | 1.0024 | 1.4756 |
| CADL | c | 1.0396 | 1.0042 | 1.0035 | 1.0070 | 1.0090 | 1.0021 | 1.4866 |
| FADL | a | 1.0599 | 1.0047 | 1.0005 | 1.0016 | 1.0005 | 0.9972 | 1.1952 |
| EDDL | b | 1.0344 | 1.0106 | 1.0023 | 1.0031 | 1.0074 | 1.0010 | 1.3685 |
| DCUR | a | 1.0531 | 1.0041 | 1.0008 | 1.0032 | 1.0082 | 1.0005 | 1.2722 |
| BDDL | b | 1.0239 | 1.0076 | 1.0005 | 1.0011 | 1.0079 | 0.9986 | 1.4516 |
| DADL | a | 1.0415 | 1.0047 | 0.9999 | 1.0034 | 1.0060 | 1.0001 | 1.0918 |
| DAUR | b | 1.0353 | 1.0082 | 1.0019 | 1.0027 | 1.0099 | 1.0011 | 1.3126 |
| DCDL | a | 1.0579 | 1.0036 | 1.0002 | 1.0029 | 1.0061 | 1.0000 | 1.1922 |
| ECDL | a | 1.0586 | 1.0052 | 1.0010 | 1.0014 | 1.0026 | 0.9995 | 1.1962 |
| ORG2 | a | 1.0575 | 1.0114 | 0.9999 | 1.0006 | 1.0029 | 1.0024 | 1.1074 |
| ADDR | b | 1.0685 | 1.0051 | 1.0003 | 1.0010 | 1.0010 | 0.9978 | 1.2186 |
| CCDR | c | 1.0597 | 1.0000 | 0.9980 | 1.0026 | 1.0024 | 0.9989 | 1.2953 |
| BCUR | c | 1.0655 | 1.0034 | 1.0000 | 0.9996 | 0.9995 | 0.9978 | 1.1666 |
| BCUL | c | 1.0737 | 1.0047 | 0.9991 | 0.9991 | 0.9989 | 0.9972 | 1.2126 |
| DCDL | c | 1.0756 | 1.0006 | 1.0036 | 1.0080 | 1.0065 | 1.0044 | 1.2120 |
| ECUL | c | 1.0131 | 1.0119 | 1.0018 | 1.0040 | 1.0106 | 1.0020 | 1.9210 |
| DDUL | a | 1.0650 | 1.0020 | 1.0024 | 1.0071 | 1.0098 | 1.0053 | 1.1356 |
| DDDR | b | 1.0209 | 1.0066 | 1.0009 | 1.0044 | 1.0142 | 1.0040 | 1.4893 |
| FCDR | c | 1.0691 | 1.0035 | 0.9992 | 1.0011 | 1.0005 | 0.9994 | 1.2657 |
| EDDL | b | 1.0272 | 1.0075 | 1.0015 | 1.0032 | 1.0083 | 1.0016 | 1.4589 |
| DDUR | a | 1.0595 | 1.0032 | 0.9979 | 1.0024 | 1.0058 | 1.0007 | 1.1544 |
| BAUR | c | 1.0656 | 1.0010 | 0.9992 | 1.0002 | 1.0018 | 0.9981 | 1.2667 |
| FCUL | a | 1.0593 | 1.0058 | 1.0011 | 1.0028 | 0.9993 | 0.9995 | 1.2237 |
| DDUL | b | 1.0526 | 1.0014 | 1.0041 | 1.0066 | 1.0096 | 1.0038 | 1.1660 |
| CAUL | c | 1.0508 | 0.9978 | 0.9991 | 1.0040 | 0.9996 | 0.9984 | 1.3209 |
| FCUL | c | 1.0934 | 1.0111 | 1.0005 | 0.9999 | 0.9985 | 1.0003 | 1.0906 |
| BCDR | c | 1.0759 | 1.0070 | 1.0012 | 0.9987 | 0.9989 | 0.9969 | 1.1149 |
| FADL | c | 1.0623 | 1.0034 | 1.0071 | 1.0036 | 1.0004 | 1.0050 | 1.1853 |
| BDUR | c | 1.0387 | 1.0059 | 0.9999 | 1.0003 | 1.0023 | 0.9978 | 1.4100 |
| DADL | c | 1.0596 | 0.9999 | 0.9990 | 1.0044 | 1.0083 | 1.0009 | 1.3642 |
| CDDL | c | 1.0635 | 1.0025 | 1.0037 | 1.0088 | 1.0060 | 1.0048 | 1.1011 |
| DAUR | c | 1.0582 | 1.0032 | 1.0015 | 1.0026 | 1.0081 | 1.0012 | 1.4972 |
| EDUL | c | 1.0766 | 1.0035 | 1.0011 | 1.0029 | 1.0034 | 0.9998 | 1.3198 |
| CCUL | c | 1.0670 | 1.0007 | 0.9994 | 1.0019 | 0.9997 | 0.9980 | 1.2670 |
| CCDL | c | 1.0669 | 1.0013 | 0.9996 | 1.0013 | 0.9997 | 0.9983 | 1.2418 |
| BCDL | c | 1.0663 | 1.0008 | 0.9989 | 1.0003 | 0.9998 | 0.9980 | 1.1570 |
| DCUL | c | 1.0562 | 1.0022 | 1.0009 | 1.0028 | 1.0095 | 1.0010 | 1.4230 |
| AADL | c | 1.0395 | 1.0051 | 1.0004 | 1.0006 | 1.0027 | 0.9989 | 1.9306 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CDDR | c | 1.0566 | 0.9981 | 0.9999 | 1.0064 | 1.0011 | 0.9982 | 1.2364 |
| AAUR | c | 1.0653 | 1.0068 | 1.0000 | 0.9997 | 1.0010 | 0.9968 | 1.2392 |
| DDDR | c | 1.0749 | 1.0016 | 1.0042 | 1.0064 | 1.0036 | 1.0050 | 1.0938 |
| AAUL | c | 1.0764 | 1.0075 | 1.0003 | 1.0018 | 1.0049 | 1.0033 | 1.0618 |

For each structure, KIEs were calculated at 213 K relative to the lowest energy conformation of permethyl-glucose bis-trifluoromethyl sulfonate (used previously as the reference for the $S_N1$ analysis). All KIEs were calculated with unscaled vibrational frequencies and employed the Bell tunneling correction.[27]

The transition states were classified into three types by the coordination geometry of sodium: (a) bound to alkoxide (red); (b) bridging (green); and (c) bound to sulfonate (blue). These transition states spanned a range of geometries:

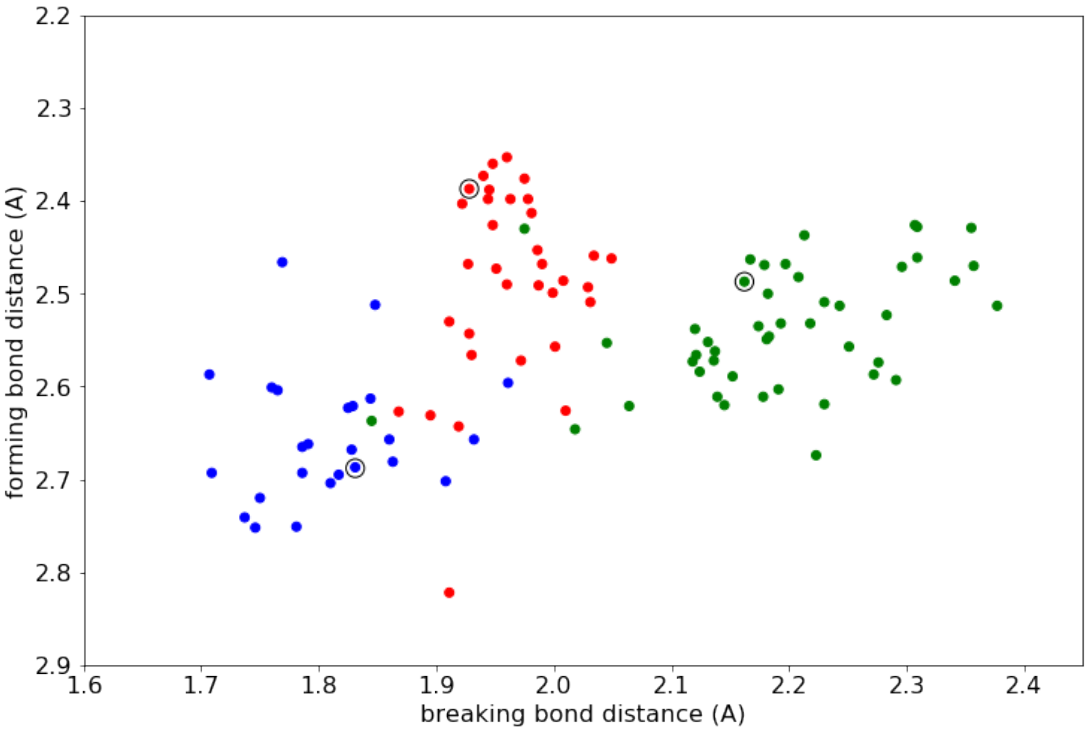
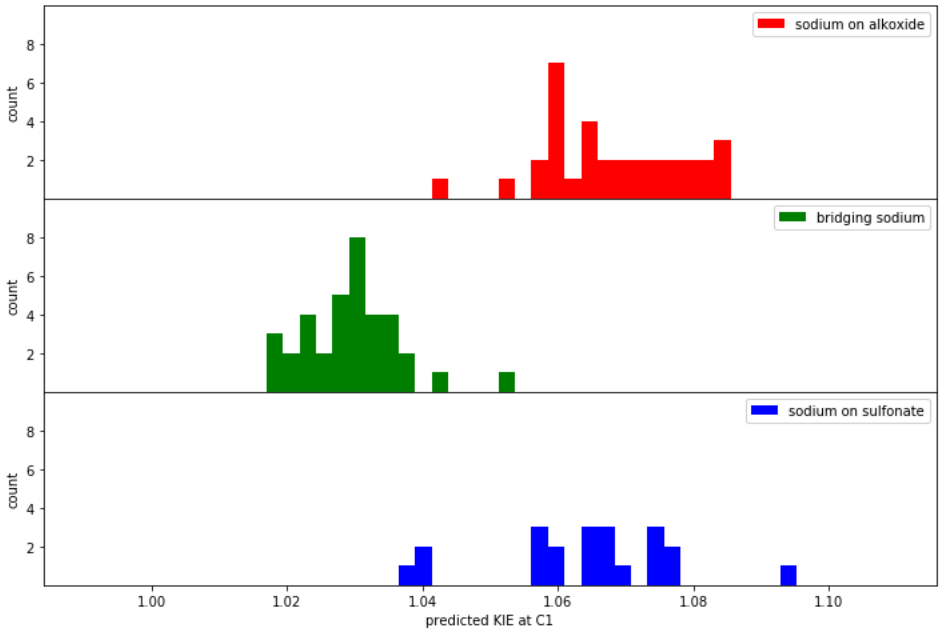
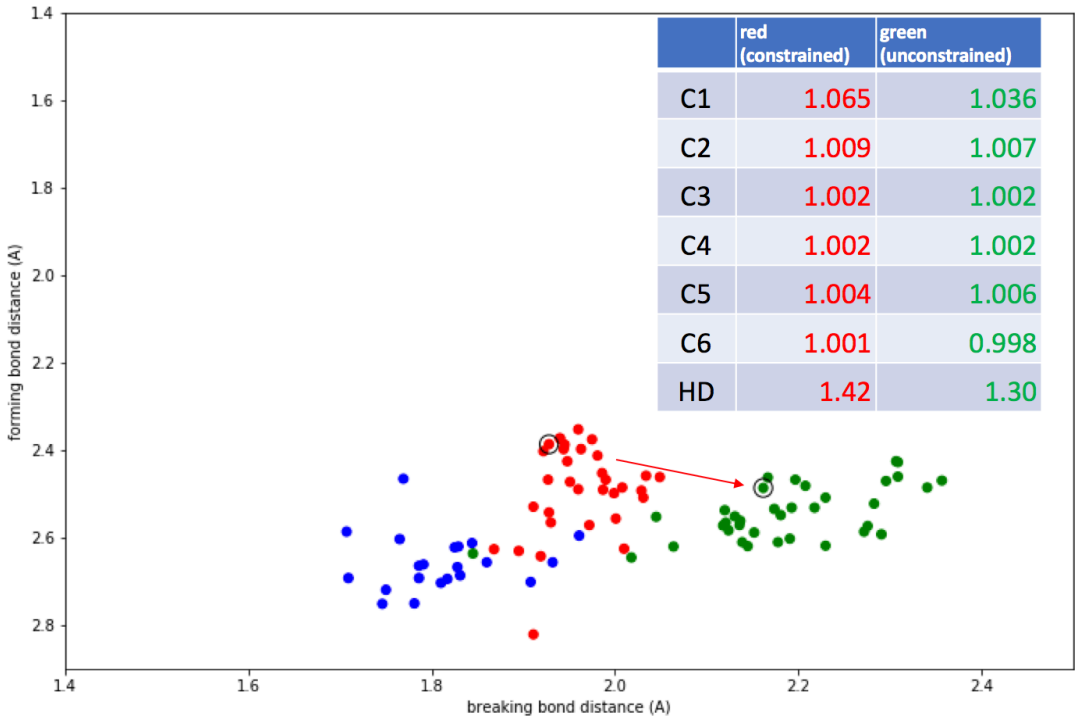



**Figure S6.** Transition structures for glycosylation. The highlighted points are the lowest-energy structures within each transition state type. The green transition states are consistent with experiment.

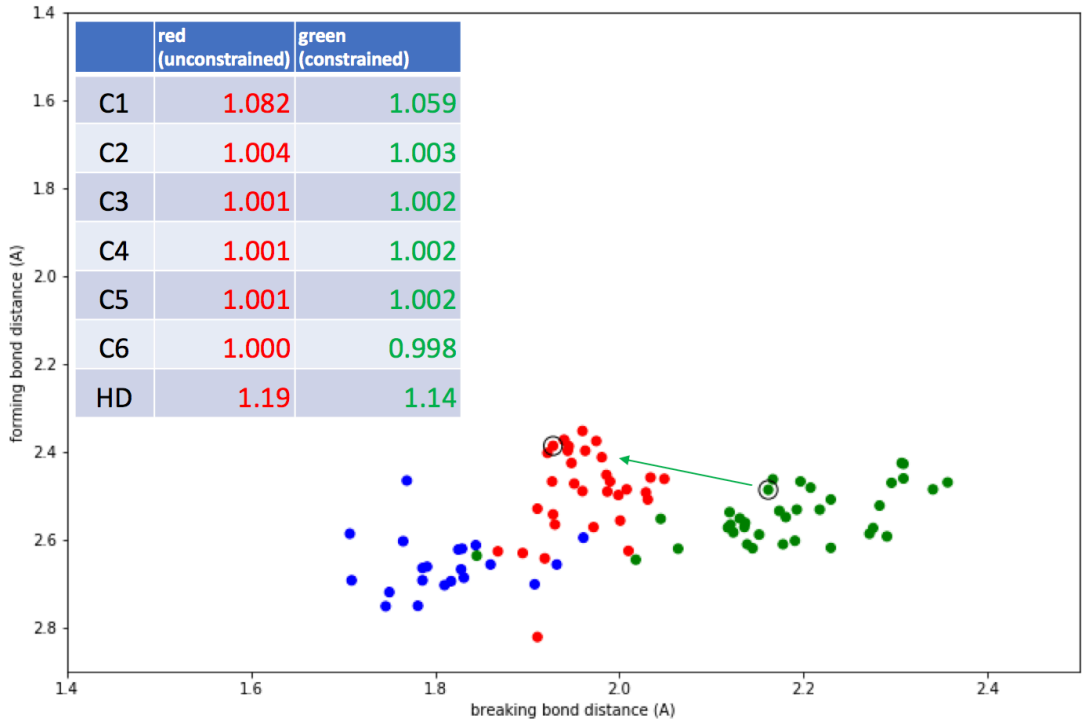
The KIE at C1 was particularly characteristic of each transition state type:




To examine the validity of the constrained transition state approach, the lowest-energy type a structure was constrained to the forming and breaking bond distances of the lowest energy type b structure (and vice versa). The results were:




| | red (constrained) | green (unconstrained) |
|---|---|---|
| C1 | 1.065 | 1.036 |
| C2 | 1.009 | 1.007 |
| C3 | 1.002 | 1.002 |
| C4 | 1.002 | 1.002 |
| C5 | 1.004 | 1.006 |
| C6 | 1.001 | 0.998 |
| HD | 1.42 | 1.30 |




| | red (unconstrained) | green (constrained) |
|---|---|---|
| C1 | 1.082 | 1.059 |
| C2 | 1.004 | 1.003 |
| C3 | 1.001 | 1.002 |
| C4 | 1.001 | 1.002 |
| C5 | 1.001 | 1.002 |
| C6 | 1.000 | 0.998 |
| HD | 1.19 | 1.14 |

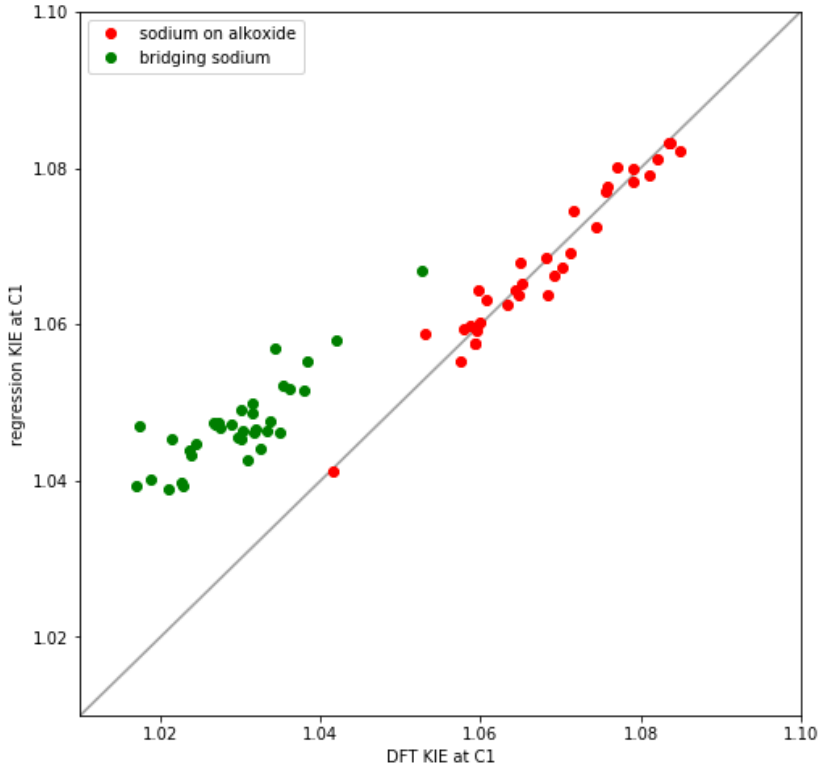
We also constructed a regression model for the type a structures:

predicted KIE at C1 =
–0.0452 x forming bond distance
–0.0321 x breaking bond distance
+ 0.0086 x imaginary frequency / 100
+ 1.2204

The fit was good:

adj. $R^2$ = 0.946
RMS error = 0.002

However, when this regression model was used for the type b structures, a substantial systematic error was observed:




Thus, it is not always true that KIEs are largely dependent on geometric parameters and independent of mechanism (or DFT method). The constrained transition state approach should be used with caution.

### 6.4. Choice of computational method for modeling $S_N2$-like glycosylations

The analysis above relied on B3LYP-D3(BJ)/6-31G*/PCM as a "standard" computational method that is expected to work reasonably well for glycosylation reactions. In this section, we consider what might have happened if we had chosen a different computational method. The lowest-energy type b transition structure (BCDR) was re-optimized with 28 other functionals:

| theory | forming | breaking | angle | imaginary |
|---|---|---|---|---|
| **b1b95** | 2.441 | 2.181 | 140.191 | 169 |
| **b3lyp** | 2.517 | 2.230 | 134.450 | 140 |
| **b3lyp_d3bj** | **2.487** | **2.162** | **138.258** | **155** |
| **b3p86** | 2.448 | 2.154 | 138.458 | 202 |
| **b971** | 2.508 | 2.209 | 135.687 | 175 |
| **b972** | 2.508 | 2.285 | 130.981 | 122 |
| **b97d** | 2.574 | 2.142 | 142.107 | 153 |
| **b97d3** | 2.576 | 2.187 | 136.883 | 108 |
| **b97d3_d3bj** | 2.558 | 2.175 | 136.971 | 108 |
| **b98** | 2.508 | 2.226 | 134.834 | 161 |
| **bhandh** | 2.290 | 2.053 | 145.758 | 307 |

| | | | | |
|---|---|---|---|---|
| **bhandhlyp** | 2.468 | 2.237 | 134.900 | 108 |
| **blyp_d3bj** | 2.560 | 2.168 | 137.511 | 117 |
| **bp86_d3bj** | 2.486 | 2.123 | 141.020 | 169 |
| **cam_b3lyp_d3bj** | 2.424 | 2.155 | 139.961 | 202 |
| **lcwpbe_d3bj** | 2.367 | 2.126 | 143.478 | 265 |
| **m062x** | 2.376 | 2.158 | 143.477 | 258 |
| **m062x_d3** | 2.375 | 2.154 | 142.944 | 270 |
| **m06_hf_d3** | 2.229 | 2.022 | 150.020 | 524 |
| **m06l_d3** | 2.549 | 2.113 | 138.465 | 101 |
| **m11** | 2.407 | 2.123 | 144.898 | 252 |
| **mpw1lyp** | 2.507 | 2.220 | 135.122 | 140 |
| **mpw1pbe** | 2.442 | 2.185 | 137.625 | 190 |
| **mpw1pw91** | 2.451 | 2.187 | 137.359 | 183 |
| **mpw3pbe** | 2.458 | 2.184 | 137.504 | 186 |
| **n12sx** | 2.434 | 2.130 | 140.091 | 243 |
| **pbe0** | 2.441 | 2.159 | 139.123 | 205 |
| **pbe0_d3bj** | 2.413 | 2.128 | 141.689 | 220 |
| **tpsstpss_d3bj** | 2.487 | 2.093 | 141.485 | 169 |

The corresponding predicted KIEs were:

| theory | C1 | C2 | C3 | C4 | C5 | C6 | HD |
|---|---|---|---|---|---|---|---|
| **b1b95** | 1.0428 | 1.0084 | 1.0027 | 1.0010 | 1.0045 | 0.9982 | 1.2420 |
| **b3lyp** | 1.0296 | 1.0087 | 1.0023 | 1.0012 | 1.0065 | 0.9982 | 1.4172 |
| **b3lyp_d3bj** | **1.0362** | **1.0072** | **1.0023** | **1.0018** | **1.0056** | **0.9981** | **1.2991** |
| **b3p86** | 1.0453 | 1.0084 | 1.0022 | 1.0009 | 1.0042 | 0.9980 | 1.3324 |
| **b971** | 1.0345 | 1.0087 | 1.0023 | 1.0013 | 1.0053 | 0.9980 | 1.5064 |
| **b972** | 1.0274 | 1.0098 | 1.0020 | 1.0012 | 1.0068 | 0.9983 | 1.5301 |
| **b97d** | 1.0352 | 1.0049 | 1.0017 | 1.0023 | 1.0061 | 0.9968 | 1.1909 |
| **b97d3** | 1.0271 | 1.0067 | 1.0021 | 1.0021 | 1.0060 | 0.9976 | 1.3631 |
| **b97d3_d3bj** | 1.0269 | 1.0077 | 1.0025 | 1.0017 | 1.0055 | 0.9980 | 1.4015 |
| **b98** | 1.0320 | 1.0090 | 1.0023 | 1.0013 | 1.0059 | 0.9980 | 1.5062 |
| **bhandh** | 1.0742 | 1.0052 | 1.0024 | 1.0021 | 1.0035 | 0.9983 | 1.1051 |
| **bhandhlyp** | 1.0297 | 1.0095 | 1.0023 | 1.0011 | 1.0073 | 0.9987 | 1.3214 |
| **blyp_d3bj** | 1.0268 | 1.0066 | 1.0025 | 1.0024 | 1.0054 | 0.9977 | 1.3708 |
| **bp86_d3bj** | 1.0382 | 1.0061 | 1.0020 | 1.0020 | 1.0045 | 0.9978 | 1.3159 |
| **cam_b3lyp_d3bj** | 1.0464 | 1.0073 | 1.0022 | 1.0015 | 1.0047 | 0.9981 | 1.2215 |
| **lcwpbe_d3bj** | 1.0633 | 1.0069 | 1.0023 | 1.0010 | 1.0040 | 0.9983 | 1.2086 |
| **m062x** | 1.0607 | 1.0068 | 1.0028 | 1.0013 | 1.0042 | 0.9983 | 1.1215 |
| **m062x_d3** | 1.0611 | 1.0067 | 1.0031 | 1.0016 | 1.0043 | 0.9983 | 1.1458 |
| **m06_hf_d3** | 1.1153 | 1.0031 | 1.0027 | 1.0011 | 1.0004 | 0.9977 | 1.0234 |
| **m06l_d3** | 1.0322 | 1.0078 | 1.0041 | 1.0019 | 1.0058 | 0.9982 | 1.3699 |
| **m11** | 1.0560 | 1.0056 | 1.0033 | 1.0013 | 1.0037 | 0.9981 | 1.1151 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **mpw1lyp** | 1.0307 | 1.0085 | 1.0023 | 1.0014 | 1.0064 | 0.9982 | 1.3750 |
| **mpw1pbe** | 1.0438 | 1.0091 | 1.0024 | 1.0008 | 1.0048 | 0.9980 | 1.3521 |
| **mpw1pw91** | 1.0424 | 1.0091 | 1.0024 | 1.0008 | 1.0050 | 0.9980 | 1.3537 |
| **mpw3pbe** | 1.0424 | 1.0088 | 1.0025 | 1.0010 | 1.0049 | 0.9979 | 1.3564 |
| **n12sx** | 1.0531 | 1.0074 | 1.0022 | 1.0014 | 1.0037 | 0.9983 | 1.3034 |
| **pbe0** | 1.0472 | 1.0086 | 1.0024 | 1.0010 | 1.0043 | 0.9981 | 1.3172 |
| **pbe0_d3bj** | 1.0519 | 1.0072 | 1.0024 | 1.0014 | 1.0043 | 0.9979 | 1.2553 |
| **tpsstpss_d3bj** | 1.0391 | 1.0060 | 1.0023 | 1.0021 | 1.0043 | 0.9980 | 1.3080 |

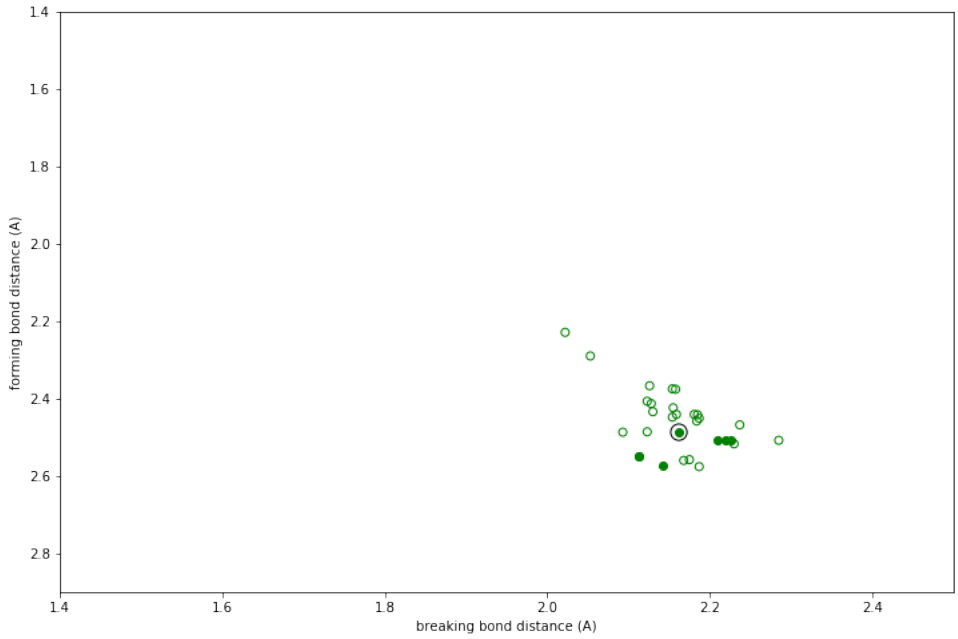



**Figure S7.** Dependence of transition structure on DFT. Each circle represents a transition state. Shaded circles give predicted KIEs at C1 that are within one standard deviation of the experimental mean. The black circle surrounds the B3LYP-D3(BJ) structure. The starting material would be in the lower right, while the product would be in the upper right. All structures used 6-31G* and PCM(THF).

Although the transition structures predicted by various DFTs are qualitatively similar, the predicted KIEs at C1 span a broad range from 1.027 to 1.115 with an average value of 1.044. Furthermore, the above plot suggests a positive correlation between the forming and breaking bond distances (note the inverted y-axis). This correlation can be interpreted as different DFTs varying in the degree to which they predict "tight" or "loose" transition states.

Furthermore, there is a strong correlation between the forming bond length and the predicted KIE at C1:

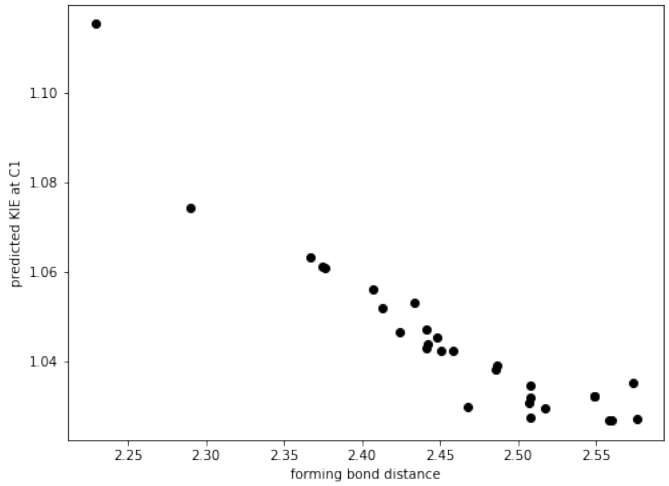



**Figure S8.** The predicted KIEs at C1 across 29 DFTs are highly correlated with the forming bond distance.

This result suggests that, although a variety of geometries can be obtained by varying the choice of DFT, only a few of those geometries will be consistent with experiment. Furthermore, Figure S7 also suggests that B3LYP-D3(BJ) predicts an "average" geometry with respect to the predictions of other functionals. To explore this idea in more detail, we performed a principal components analysis (PCA). A range of geometric parameters were taken as features: the forming bond distance, the breaking bond distance, the nucleophile-C1-leaving-group angle, the sodium alkoxide distance, the sodium-sulfonate oxygen bond distance, the C1-sodium-sulfonate oxygen bond angle, and the C6-O-C1-nucleophile dihedral angle. Each feature was normalized to a mean of 0 and a standard deviation of 1. Then, a PCA analysis was performed (on all 8 dimensions). The explained variance for each parameter was (values in %):

```
principal component 1 (PC1): 61.47%
principal component 2 (PC2): 17.08%
principal component 3 (PC3): 12.49%
principal component 4 (PC4): 5.55%
principal component 5 (PC5): 2.53%
principal component 6 (PC6): 0.61%
principal component 7 (PC7): 0.26%
principal component 8 (PC8): 0.00%
```

Thus, the first principal component (PC1) and second principal component (PC2) explained 79% of the variance. B3LYP-D3(BJ) is also near the centroid in PCA space:

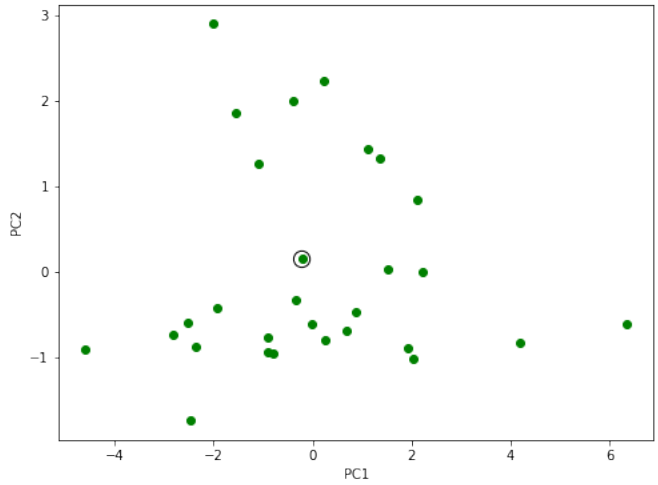



**Figure S9.** Principal components analysis of the transition structures predicted by various DFTs. The B3LYP-D3(BJ) geometry is near the centroid and can be considered a "typical" prediction.

The finding that B3LYP-D3(BJ) is a "typical" prediction indicates that the good agreement between theory and experiment cannot be ascribed to the fortuitous generation of an implausible geometry, due to an unexpected deficiency of B3LYP-D3(BJ). While further benchmark studies, will be necessary to evaluate the accuracy of B3LYP-D3(BJ) as a method for predicting glycosylation KIEs, the results above provide reasonable ground to choose B3LYP-D3(BJ) as an interim method.

Having addressed the choice of DFT, we turned our attention to the choice of basis set, which might be expected to have a significant effect here. The model system involves two anions: the alkoxide and the sulfonate. As a result, it is reasonable to expect that diffuse functions might be important. Unfortunately, the system is quite large and suffered from numerical convergence issues when calculating frequencies. (Surprisingly, the energy and gradient calculations worked normally.) Both the 6-31+G* and jun-cc-pVDZ basis sets, which constitute very mild levels of augmentation, failed to converge. However, it was possible to place the diffuse functions of the 6-31+G* basis set on the alkoxide and sulfonate oxygens to create a "locally dense" basis set. In the archived files, this basis set is denoted as the `custom` basis.

We attempted to locate the analogous transition structures using the `custom` basis. Of the 29 transition structures found previously with 6-31G*, 22 analogous transition structures were found with the `custom` basis (the other 7 did not converge in geometry after repeated attempts):

| theory | forming | breaking | angle | imaginary |
|---|---|---|---|---|
| **b1b95** | 2.529 | 2.219 | 135.909 | 108 |
| **b3lyp_d3bj** | **2.562** | **2.176** | **135.695** | **104** |

| | | | | |
|---|---|---|---|---|
| **b971** | 2.584 | 2.279 | 130.793 | 67 |
| **b972** | 2.578 | 2.447 | 125.566 | 62 |
| **b97d** | 2.660 | 2.120 | 140.002 | 134 |
| **b97d3** | 2.679 | 2.135 | 134.909 | 87 |
| **b98** | 2.579 | 2.285 | 131.179 | 68 |
| **bhandh** | 2.328 | 2.075 | 144.351 | 260 |
| **bp86_d3bj** | 2.563 | 2.126 | 138.328 | 124 |
| **cam_b3lyp_d3bj** | 2.497 | 2.188 | 137.579 | 132 |
| **lcwpbe_d3bj** | 2.429 | 2.180 | 140.747 | 184 |
| **m062x** | 2.438 | 2.175 | 141.126 | 196 |
| **m062x_d3** | 2.440 | 2.165 | 140.689 | 212 |
| **m06_hf_d3** | 2.308 | 2.115 | 145.832 | 358 |
| **m06l_d3** | 2.622 | 2.094 | 135.358 | 87 |
| **m11** | 2.489 | 2.132 | 141.717 | 194 |
| **mpw1pbe** | 2.499 | 2.244 | 133.707 | 120 |
| **mpw1pw91** | 2.506 | 2.246 | 133.416 | 115 |
| **mpw3pbe** | 2.520 | 2.240 | 133.561 | 118 |
| **n12sx** | 2.514 | 2.197 | 135.993 | 151 |
| **pbe0_d3bj** | 2.468 | 2.154 | 139.714 | 175 |
| **tpsstpss_d3bj** | 2.558 | 2.092 | 139.374 | 130 |

The computed KIEs were:

| theory | C1 | C2 | C3 | C4 | C5 | C6 | HD |
|---|---|---|---|---|---|---|---|
| **b1b95** | 1.0310 | 1.0081 | 1.0017 | 1.0015 | 1.0065 | 0.9977 | 1.3278 |
| **b3lyp_d3bj** | **1.0267** | **1.0075** | **1.0023** | **1.0022** | **1.0064** | **0.9984** | **1.3195** |
| **b971** | 1.0177 | 1.0086 | 1.0020 | 1.0019 | 1.0072 | 0.9990 | 1.3911 |
| **b972** | 1.0137 | 1.0104 | 1.0020 | 1.0014 | 1.0080 | 0.9988 | 1.6047 |
| **b97d** | 1.0299 | 1.0049 | 1.0020 | 1.0028 | 1.0064 | 0.9969 | 1.2048 |
| **b97d3** | 1.0223 | 1.0064 | 1.0022 | 1.0023 | 1.0060 | 0.9978 | 1.3276 |
| **b98** | 1.0176 | 1.0087 | 1.0020 | 1.0019 | 1.0071 | 0.9989 | 1.3943 |
| **bhandh** | 1.0647 | 1.0062 | 1.0026 | 1.0023 | 1.0041 | 0.9984 | 1.1277 |
| **bp86_d3bj** | 1.0300 | 1.0065 | 1.0022 | 1.0024 | 1.0052 | 0.9981 | 1.3398 |
| **cam_b3lyp_d3bj** | 1.0336 | 1.0082 | 1.0023 | 1.0018 | 1.0057 | 0.9984 | 1.2505 |
| **lcwpbe_d3bj** | 1.0469 | 1.0085 | 1.0024 | 1.0012 | 1.0049 | 0.9986 | 1.2571 |
| **m062x** | 1.0488 | 1.0072 | 1.0028 | 1.0018 | 1.0050 | 0.9986 | 1.1226 |
| **m062x_d3** | 1.0497 | 1.0072 | 1.0031 | 1.0018 | 1.0046 | 0.9984 | 1.1700 |
| **m06_hf_d3** | 1.0775 | 1.0053 | 1.0024 | 1.0010 | 1.0018 | 0.9980 | 1.0203 |
| **m06l_d3** | 1.0283 | 1.0072 | 1.0036 | 1.0021 | 1.0059 | 0.9978 | 1.4490 |
| **m11** | 1.0444 | 1.0063 | 1.0034 | 1.0016 | 1.0042 | 0.9984 | 1.1460 |
| **mpw1pbe** | 1.0303 | 1.0097 | 1.0022 | 1.0015 | 1.0061 | 0.9984 | 1.4264 |
| **mpw1pw91** | 1.0290 | 1.0096 | 1.0022 | 1.0015 | 1.0063 | 0.9985 | 1.4277 |
| **mpw3pbe** | 1.0287 | 1.0095 | 1.0021 | 1.0015 | 1.0061 | 0.9984 | 1.4273 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **n12sx** | 1.0357 | 1.0090 | 1.0025 | 1.0016 | 1.0049 | 0.9986 | 1.3010 |
| **pbe0_d3bj** | 1.0421 | 1.0080 | 1.0023 | 1.0015 | 1.0048 | 0.9980 | 1.2757 |
| **tpsstpss_d3bj** | 1.0315 | 1.0065 | 1.0023 | 1.0022 | 1.0044 | 0.9982 | 1.3165 |

In general, the transition states were looser. The forming bond length was somewhat longer:

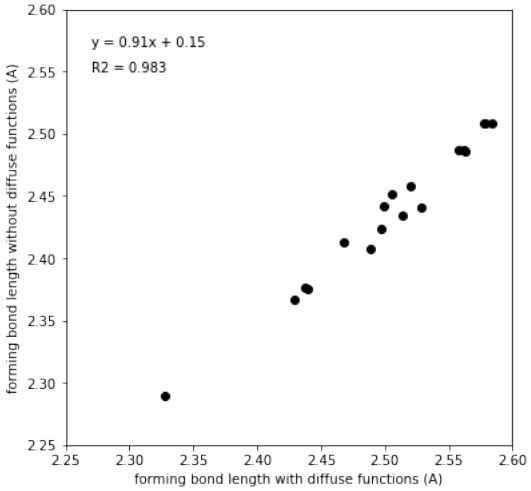



**Figure S10.** Breaking bond lengths increased with the addition of diffuse functions.

The breaking bond length was modestly increased as well:

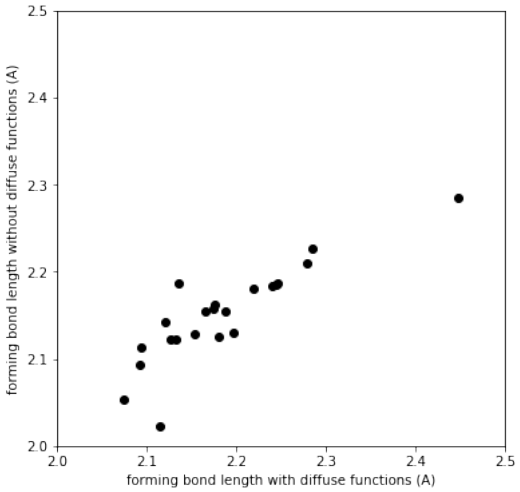



**Figure S11.** The forming bond lengths also increased with the addition of diffuse functions.

There was also a striking dependence between the predicted KIE at C1 and the breaking bond length:

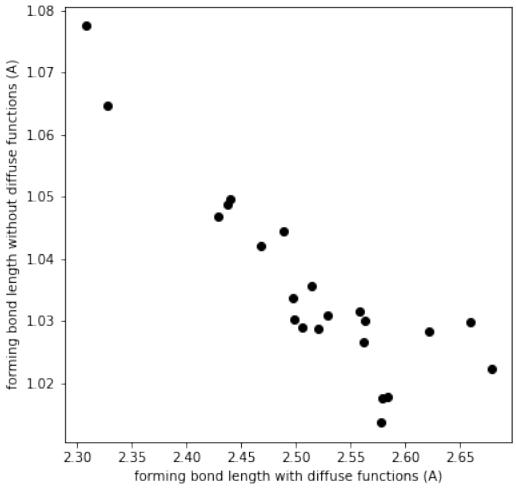



**Figure S12.** The KIE at C1 depends strongly on the forming bond length.

Interestingly, the geometries that were consistent with experiment remained in a similar region of the reaction coordinate (Figure S13). While B3LYP-D3(BJ) was within experimental error with the 6-31G* basis set (1.036 predicted vs. 1.034±0.004 experimental), it was modestly outside of experimental error with the `custom` basis set (1.027±0.004). However, the geometries that reproduced experiment were from a very similar region of the reaction coordinate.

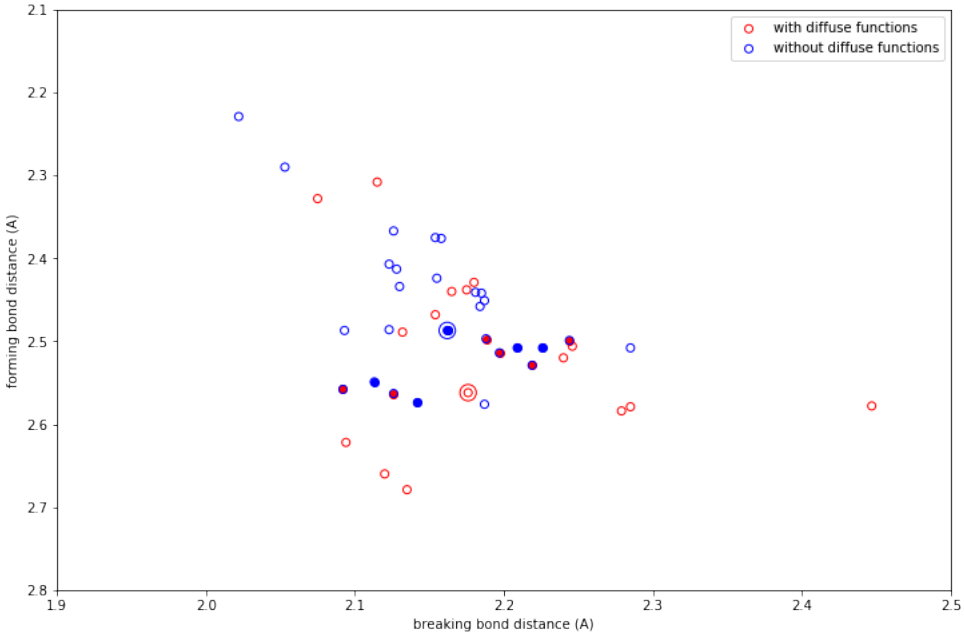



**Figure S13.** Agreement between transition structure and the experimental KIE at C1. Calculations with (red) and without (blue) diffuse functions

gave structures in a similar region of the reaction coordinate. Some structures were consistent with experiment (solid circles), while many were not (open circles). Both basis sets gave agreement with experiment in a similar region of the reaction coordinate. The highlighted points denote B3LYP-D3(BJ).

### 6.5. Lowest energy structure

The following are coordinates for the lowest-energy transition structure (BCDR):

```
0 1
 C                -1.82206300    1.49821800    2.21782500
 C                -2.11842700    2.32169300    0.96299600
 C                -1.24282600    3.57667200    0.92527000
 C                 0.49833200    2.51558900    2.21278700
 C                -0.32125400    1.22428100    2.32556900
 H                -1.34858400    4.08775900   -0.04141600
 H                -1.85126200    1.72940500    0.07977500
 H                -2.15201400    2.06945800    3.09517400
 H                 0.25689900    3.14815500    3.07671200
 H                -0.05262400    0.54707700    1.50888800
 O                 0.13031100    3.22143600    1.00134800
 O                -1.62543500    4.42505900    1.97008200
 O                -3.47916000    2.72023300    0.90347500
 O                -2.55470600    0.27905700    2.12836000
 O                -0.04341300    0.60557100    3.58045700
 C                 2.01814400    2.29697600    2.15383600
 H                 2.28455000    1.79993600    3.10999700
 H                 2.46281200    3.31656200    2.22435500
 O                 2.45361900    1.62507700    1.03522700
 C                -4.28309200    1.89063600    0.07674700
 H                -3.93472200    1.90708300   -0.96582300
 H                -4.28776500    0.85563800    0.43092400
 H                -5.29792300    2.29516100    0.11387200
 C                -3.08895400   -0.17136200    3.36517000
 H                -2.29736300   -0.37793700    4.09276800
 H                -3.77983000    0.57165400    3.78950100
 H                -3.63925400   -1.08899500    3.15183800
 C                 0.74977300   -0.57091900    3.47514300
 H                 0.20312100   -1.36551500    2.95424400
 H                 1.68799000   -0.38510200    2.94287400
 H                 0.97023400   -0.89498600    4.49586700
 C                 3.82240200   -1.51671200   -1.33119500
 C                 3.19719400   -0.19854600   -0.86528600
```

| | | | |
|---|---|---|---|
| C | 1.84602000 | -0.41333100 | -0.25418600 |
| C | 2.21083900 | -2.75110900 | 0.17331800 |
| C | 3.67776600 | -2.53958300 | -0.19822800 |
| H | 1.16342200 | 0.40357700 | -0.13706000 |
| H | 3.78425000 | 0.20072900 | -0.02228900 |
| H | 3.30197000 | -1.86835600 | -2.22977400 |
| H | 1.67508500 | -3.18410000 | -0.67630700 |
| H | 4.21772800 | -2.16327700 | 0.67705800 |
| O | 1.54084800 | -1.46617900 | 0.42563800 |
| O | -0.51687100 | 0.19651100 | -3.88181900 |
| O | 3.07200300 | 0.80972000 | -1.84746700 |
| O | 5.19790800 | -1.29699800 | -1.59253900 |
| O | 4.19017300 | -3.79824900 | -0.60044400 |
| C | 1.97652100 | -3.59924600 | 1.40237300 |
| H | 2.30022700 | -4.62570600 | 1.17636000 |
| H | 0.89938700 | -3.62206300 | 1.62466100 |
| O | 2.70643800 | -3.05368900 | 2.48038700 |
| S | -0.29157500 | 0.03778900 | -2.43472300 |
| O | -0.17851000 | 1.32244400 | -1.67512500 |
| O | 0.83459600 | -0.91374800 | -2.09798900 |
| C | -1.75146500 | -0.76810200 | -1.75948300 |
| C | -2.99261400 | -0.56180500 | -2.35533500 |
| C | -1.62481700 | -1.55665800 | -0.62016800 |
| C | -4.12143000 | -1.15333800 | -1.78772200 |
| H | -3.07061900 | 0.04167700 | -3.25191700 |
| C | -2.75900800 | -2.15274500 | -0.07467800 |
| H | -0.65675600 | -1.70785600 | -0.16258500 |
| C | -4.01209700 | -1.95419600 | -0.65027900 |
| H | -4.89237600 | -2.41687400 | -0.22119700 |
| C | 4.29999300 | 1.45303600 | -2.20679800 |
| H | 4.92941200 | 1.61181900 | -1.32482600 |
| H | 4.85315900 | 0.86325500 | -2.94165900 |
| H | 4.02383700 | 2.41951200 | -2.63129200 |
| C | 5.68701500 | -1.97950400 | -2.74339400 |
| H | 5.54646100 | -3.06142200 | -2.65498000 |
| H | 5.18749400 | -1.62270100 | -3.65499500 |
| H | 6.75346600 | -1.75199100 | -2.80814600 |
| C | 5.26386400 | -4.26732200 | 0.21284300 |
| H | 6.12920200 | -3.59709500 | 0.14354700 |
| H | 4.95628700 | -4.35332800 | 1.26261600 |
| H | 5.53554100 | -5.25342600 | -0.16948900 |
| C | 2.48404200 | -3.75720400 | 3.69286800 |
| H | 3.08211700 | -3.26350000 | 4.46116900 |
| H | 1.42384000 | -3.72458200 | 3.98126500 |

| | | | |
|---|---|---|---|
| H | 2.79582400 | -4.80813000 | 3.60728400 |
| C | -0.97469900 | 5.69050100 | 1.93425100 |
| H | -1.41196100 | 6.29180800 | 2.73360500 |
| H | 0.10450300 | 5.59172100 | 2.09828000 |
| H | -1.14441500 | 6.18927000 | 0.96915000 |
| Na | 1.53637400 | 2.64926800 | -0.81633100 |
| O | 3.07159800 | 4.33269300 | -1.04929100 |
| C | 3.17165200 | 5.49656500 | -1.85429700 |
| H | 4.11767200 | 5.50588700 | -2.41357500 |
| H | 2.33551300 | 5.47845100 | -2.55702300 |
| H | 3.11273400 | 6.40624600 | -1.24075800 |
| C | 4.11206700 | 4.23210000 | -0.07873000 |
| H | 4.07886300 | 5.08515900 | 0.61259900 |
| H | 3.93329800 | 3.29770800 | 0.45992100 |
| H | 5.09486800 | 4.20842000 | -0.56988800 |
| C | -5.47954000 | -0.86784900 | -2.36621100 |
| F | -6.03096300 | 0.23884600 | -1.80663300 |
| F | -6.34293000 | -1.88310000 | -2.15278600 |
| F | -5.42503400 | -0.64719300 | -3.69571500 |
| C | -2.60302000 | -3.08614400 | 1.09250200 |
| F | -1.59198400 | -2.71351300 | 1.91268800 |
| F | -2.31999300 | -4.34514600 | 0.68349000 |
| F | -3.72646300 | -3.15965100 | 1.83989300 |

### 6.6. Conclusion

Overall, our interpretation is that most commonly-used computational methods can reproduce the experimental KIEs, although the both the choice of DFT and basis set are important. The effect of the choice of DFT can be ascribed to the numerous non-covalent interactions in this system, as well as electron correlation effects in the partially formed or broken bonds. The effect of basis set is likely basis set superposition error. In turn, these effects create a range of predictions for the KIE at C1. However, the region of the reaction coordinate that agrees with experiment is remarkably small and independent of basis set. (This analysis only considered one template transition structure, so whether this is also independent of DFT choice cannot be determined.) Furthermore, B3LYP-D3(BJ) gives transition structures that are average when compared with the transition structures given by other DFTs. Thus, while the agreement with experiment obtained with B3LYP-D3(BJ)/6-31G* is likely due in part to the cancellation of errors, the predicted transition structure is meaningful and is similar to what would be predicted by other functionals in the same region of the reaction coordinate.

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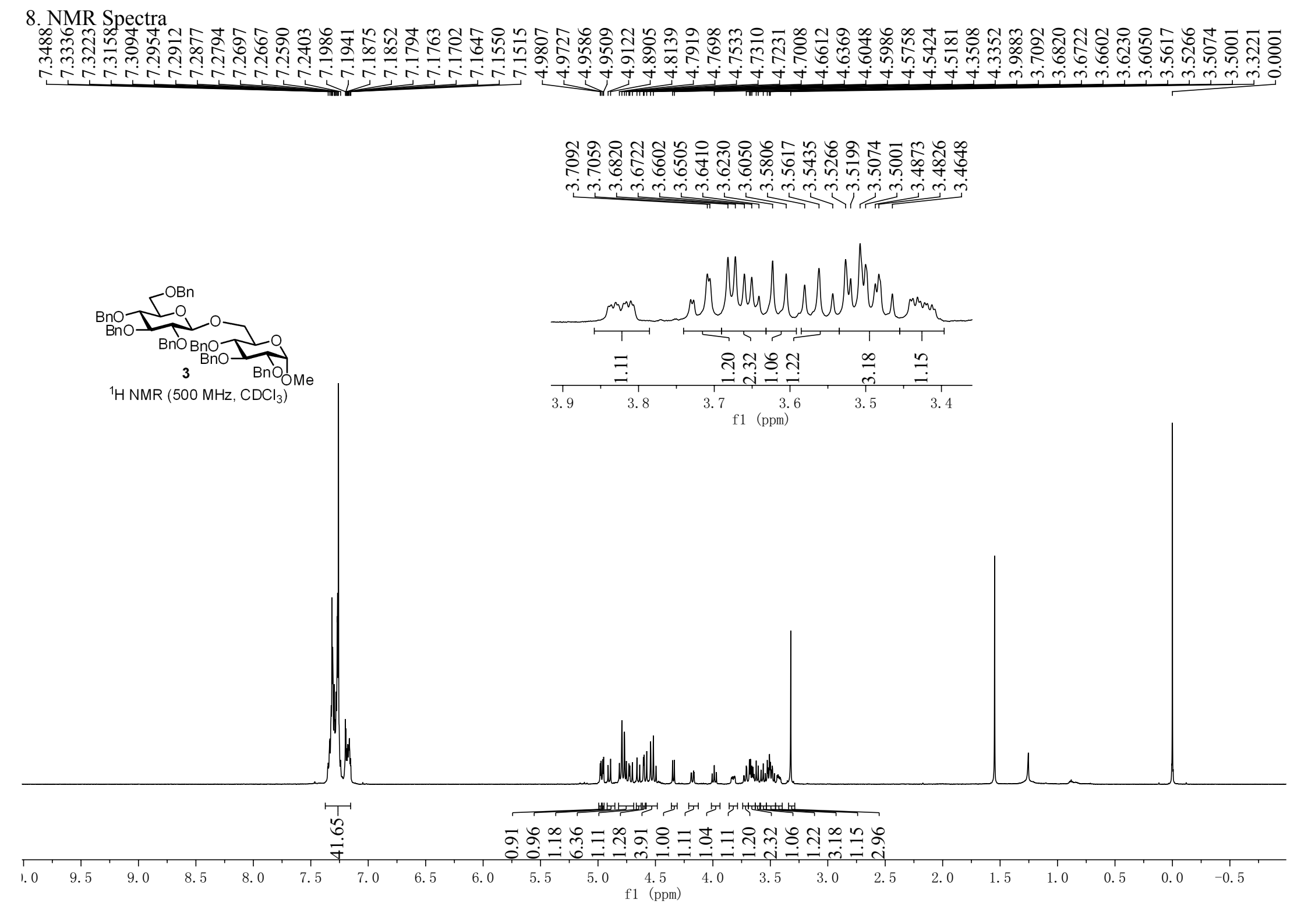
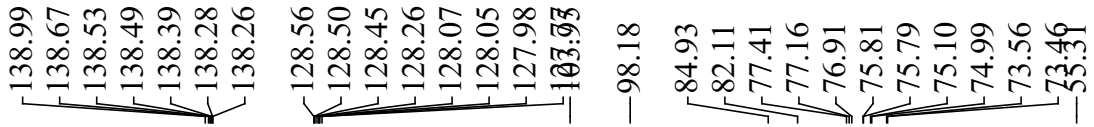
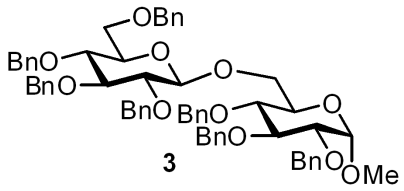
8. NMR Spectra






**3**

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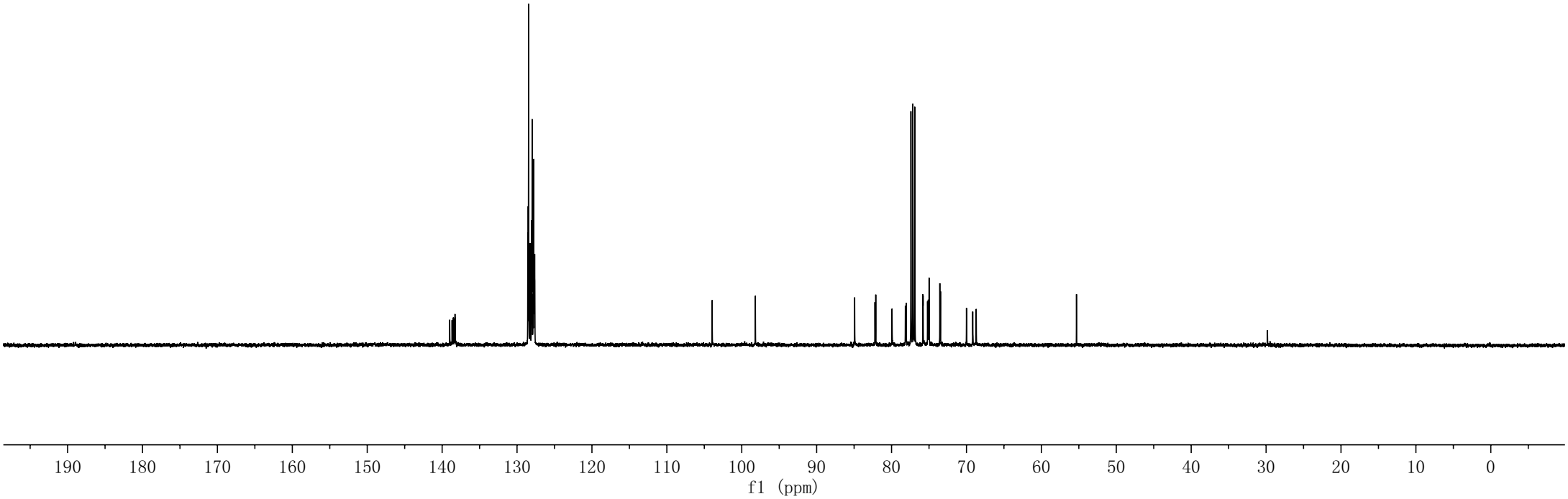

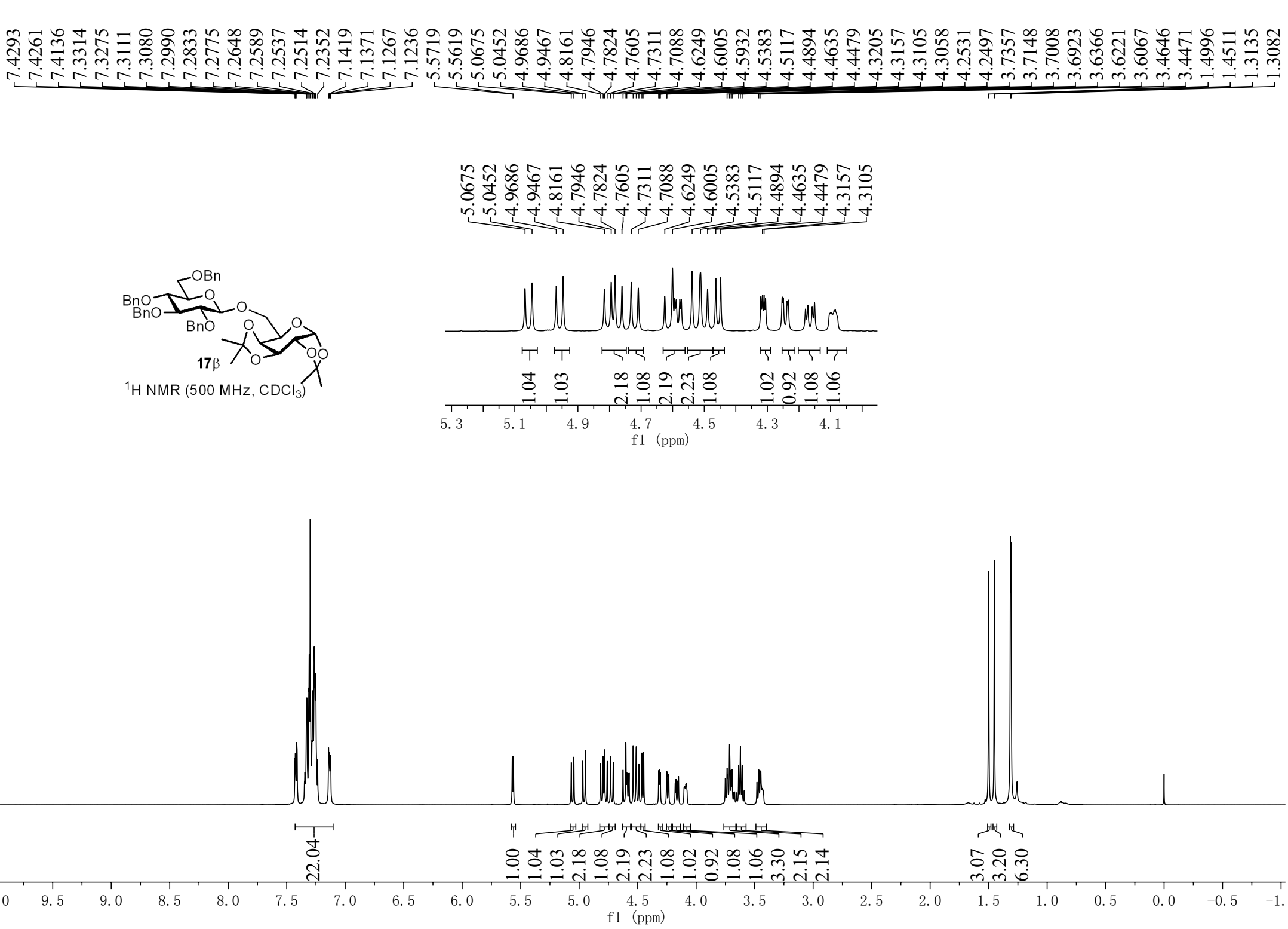
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7.2648
7.2589
7.2537
7.2514
7.2352
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7.1371
7.1267
7.1236
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5.5619
5.0675
5.0452
4.9686
4.9467
4.8161
4.7946
4.7824
4.7605
4.7311
4.7088
4.6249
4.6005
4.5932
4.5383
4.5117
4.4894
4.4635
4.4479
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3.7148
3.7008
3.6923
3.6366
3.6221
3.6067
3.4646
3.4471
1.4996
1.4511
1.3135
1.3082
OBn
BnO
BnO
BnO
O
17β
1H NMR (500 MHz, CDCl3)
1.04
1.03
2.18
1.08
2.19
2.23
1.08
1.02
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1.08
1.06
f1 (ppm)
22.04
1.00
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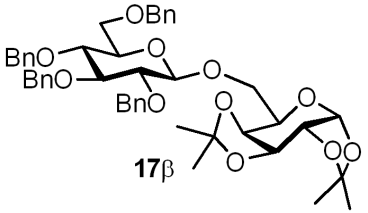
3.20
6.30
f1 (ppm)




**17**β

$^{13}$C NMR (125 MHz, $CDCl_3$)

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128.381
128.240
127.982
127.917
127.894
109.403
108.605
104.438
96.428
84.593
81.660
77.763
77.334
77.080
76.826
75.698
75.024
74.797
74.375
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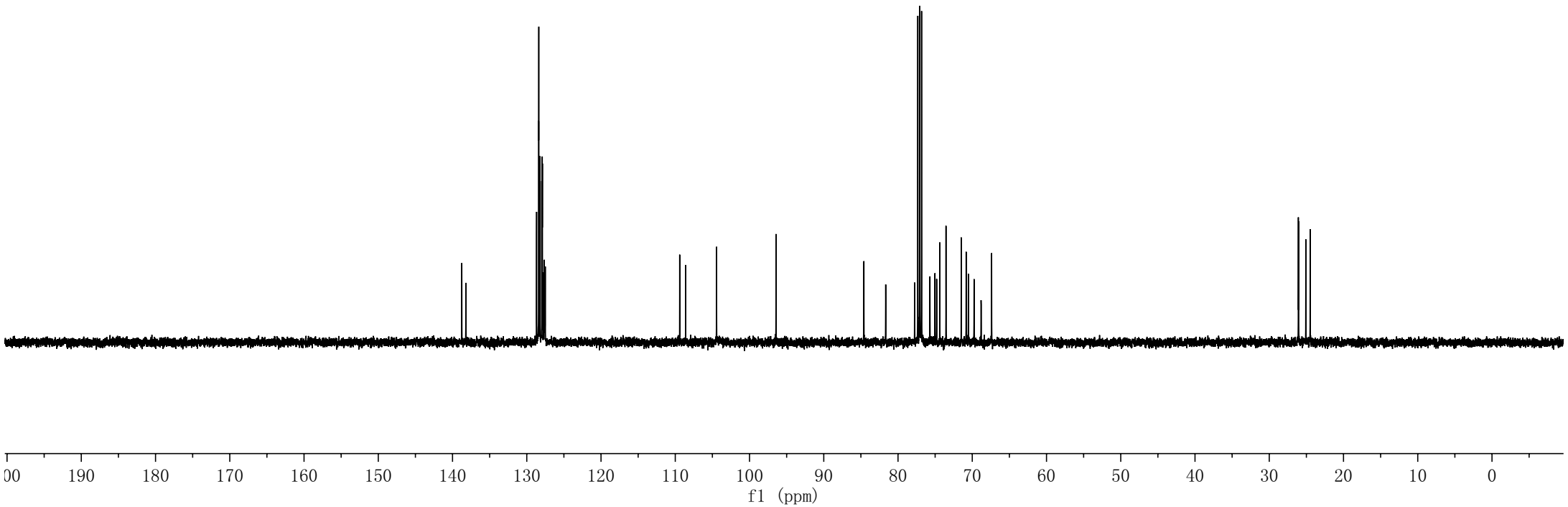
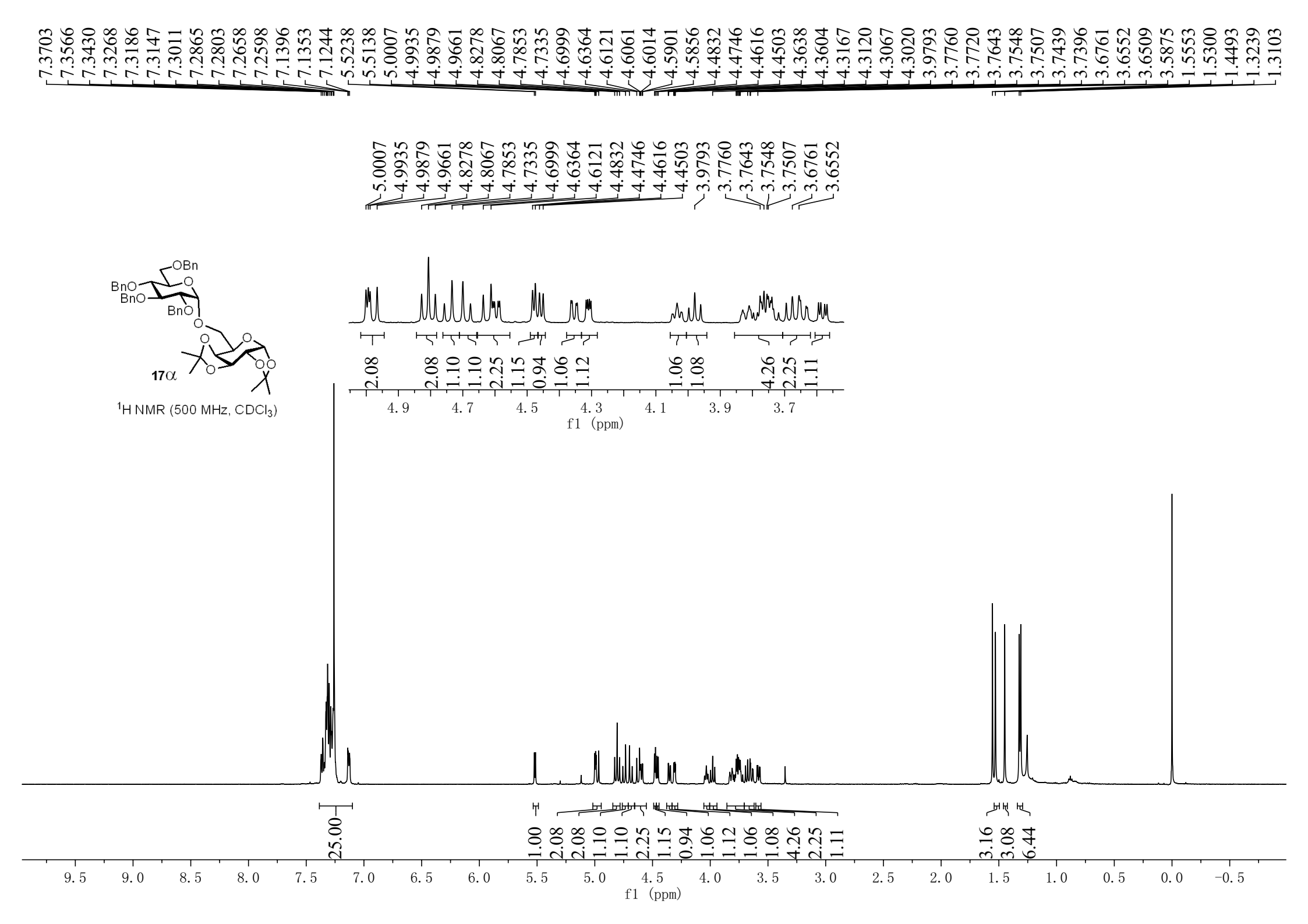
24.487

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7.2598
7.1396
7.1353
7.1244
5.5238
5.5138
5.0007
4.9935
4.9879
4.9661
4.8278
4.8067
4.7853
4.7335
4.6999
4.6364
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4.6061
4.6014
4.5901
4.5856
4.4832
4.4746
4.4616
4.4503
4.3638
4.3604
4.3167
4.3120
4.3067
4.3020
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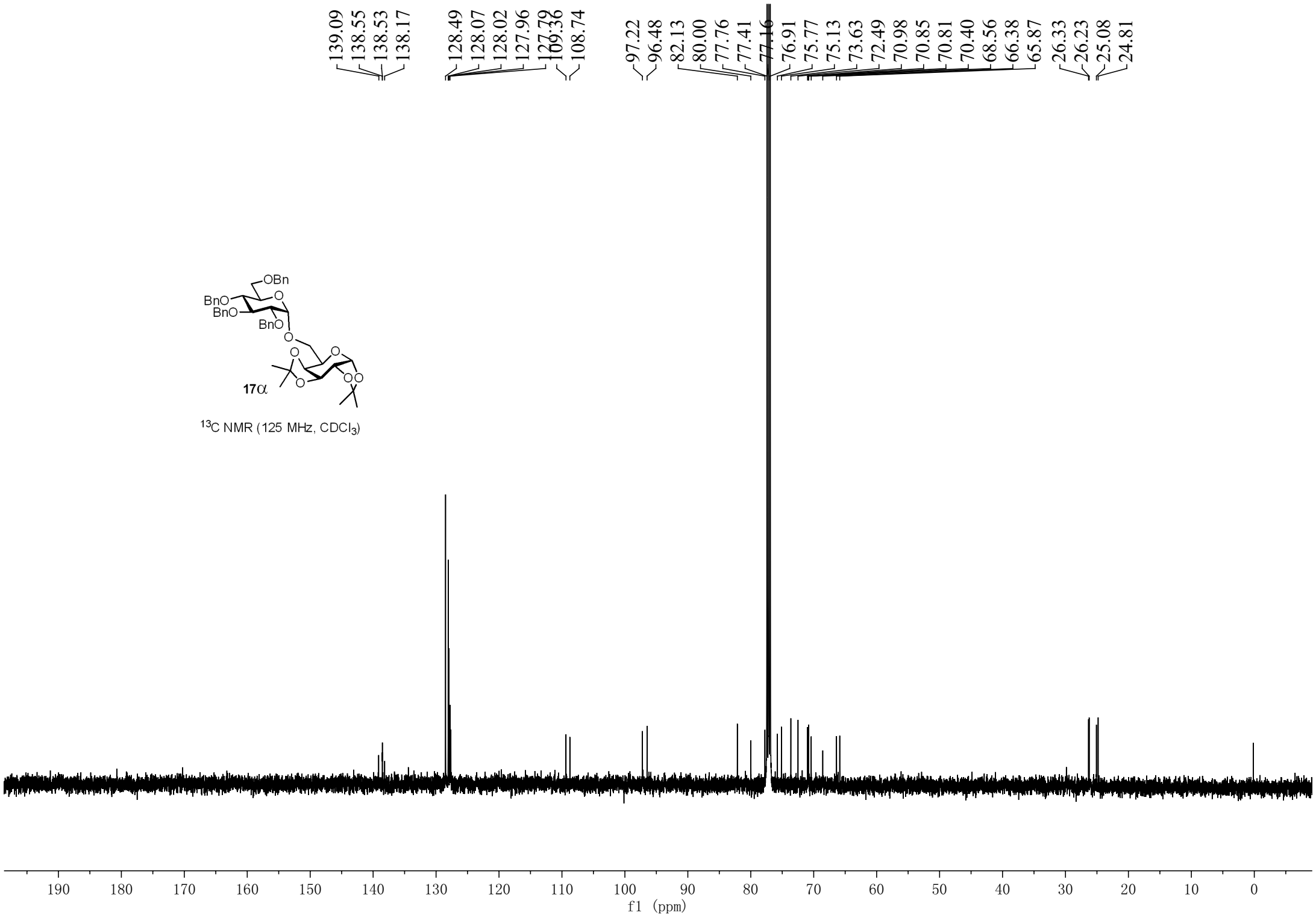
3.7760
3.7720
3.7643
3.7548
3.7507
3.7439
3.7396
3.6761
3.6552
3.6509
3.5875
1.5553
1.5300
1.4493
1.3239
1.3103
BnO
BnO
BnO
OBn
17α
1H NMR (500 MHz, CDCl3)
f1 (ppm)
f1 (ppm)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77.16
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72.49
70.98
70.85
70.81
70.40
68.56
66.38
65.87
26.33
26.23
25.08
24.81
OBn
BnO
BnO
BnO
17α
13C NMR (125 MHz, CDCl3)
190
180
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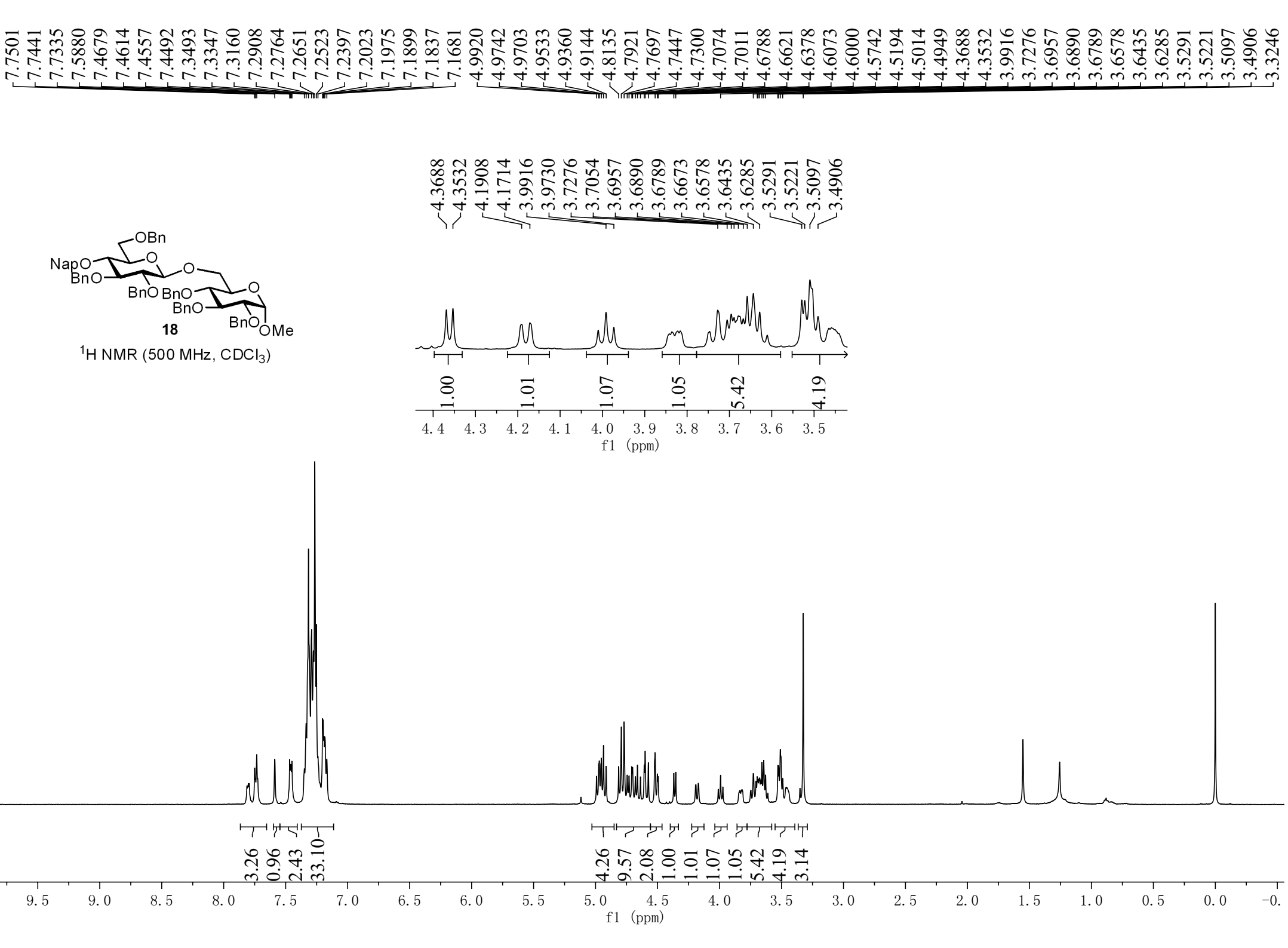
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)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7.1899
7.1837
7.1681
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4.8135
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4.7011
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4.6073
4.6000
4.5742
4.5194
4.5014
4.4949
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4.3532
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3.6435
3.6285
3.5291
3.5221
3.5097
3.4906
3.3246
OBn
NapO
BnO
BnO
BnO
BnO
BnO
OMe
18
1H NMR (500 MHz, CDCl3)
4.3688
4.3532
4.1908
4.1714
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3.9730
3.7276
3.7054
3.6957
3.6890
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3.5291
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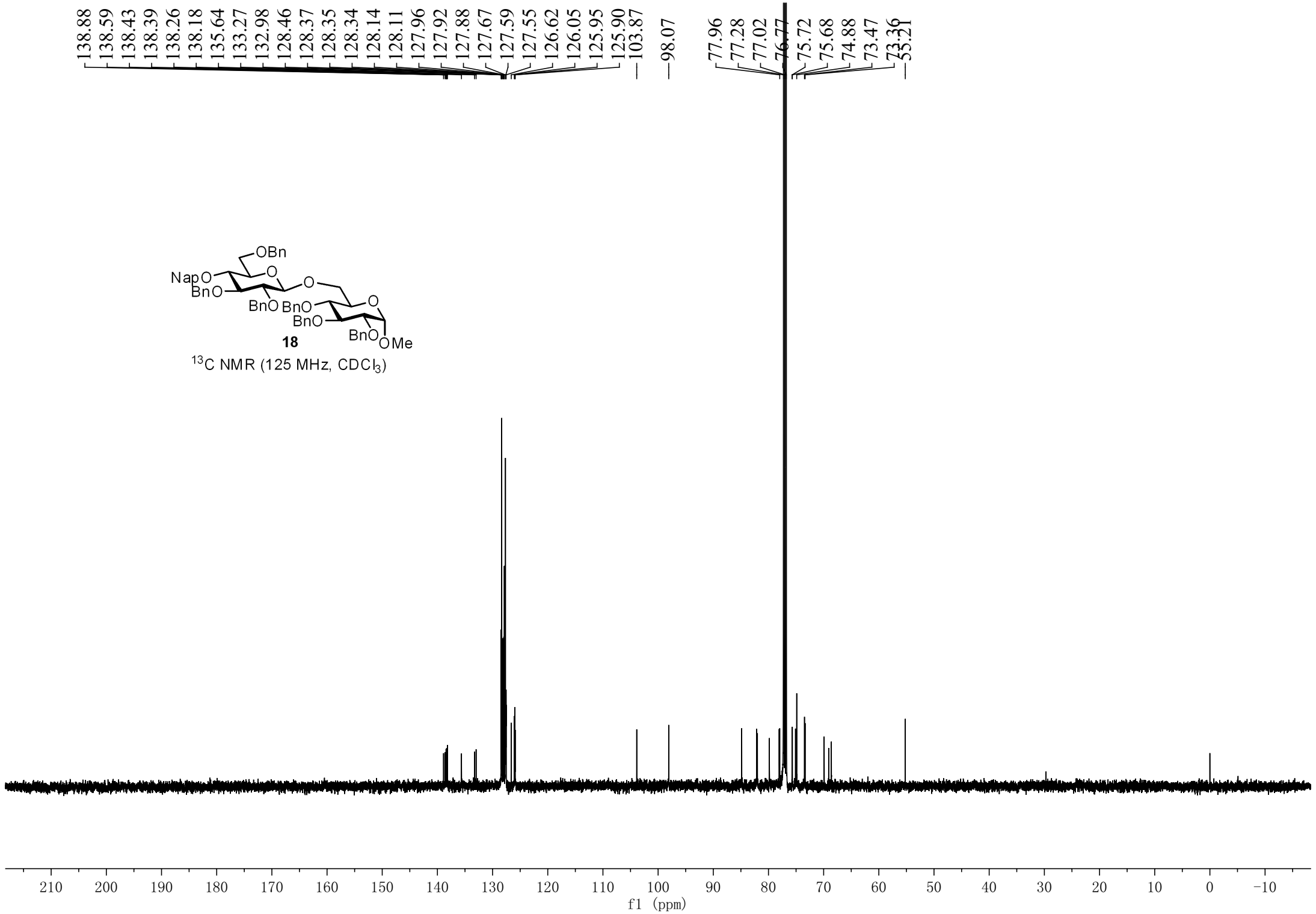
1.00
1.01
1.07
1.05
5.42
4.19
4.4 4.3 4.2 4.1 4.0 3.9 3.8 3.7 3.6 3.5
f1 (ppm)
3.26
0.96
2.43
33.10
4.26
9.57
2.08
1.00
1.01
1.07
1.05
5.42
4.19
3.14
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.
f1 (ppm)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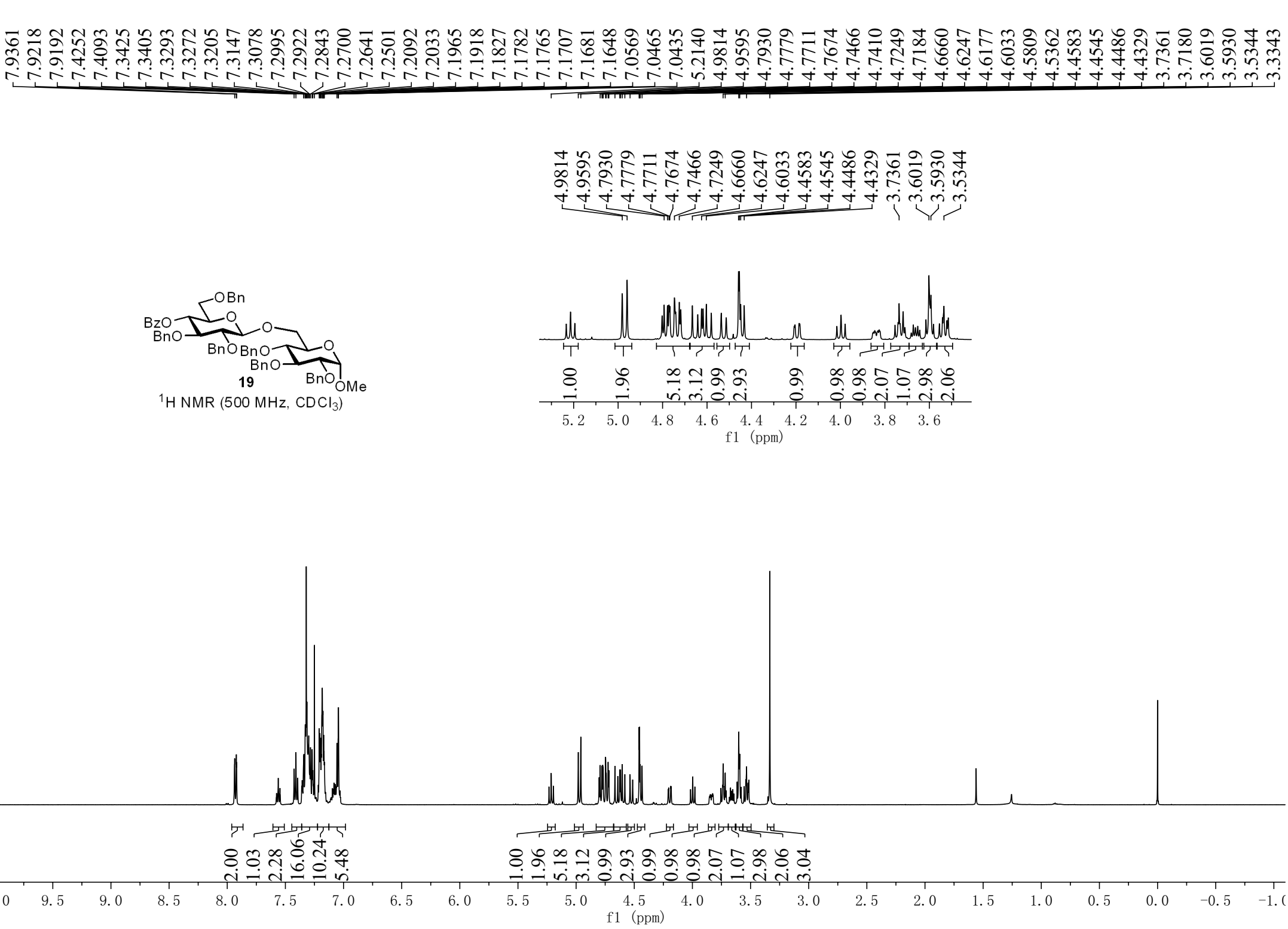
127.96
127.92
127.88
127.67
127.59
127.55
126.62
126.05
125.95
125.90
103.87
98.07
77.96
77.28
77.02
76.77
75.72
75.68
74.88
73.47
73.36
55.21
OBn
NapO
BnO
BnO
BnO
BnO
BnO
OMe
18
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)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7.3078
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7.2033
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7.1918
7.1827
7.1782
7.1765
7.1707
7.1681
7.1648
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7.0465
7.0435
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4.5362
4.4583
4.4545
4.4486
4.4329
3.7361
3.7180
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3.5930
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BzO
BnO
BnO
BnO
BnO
BnO
OMe
19
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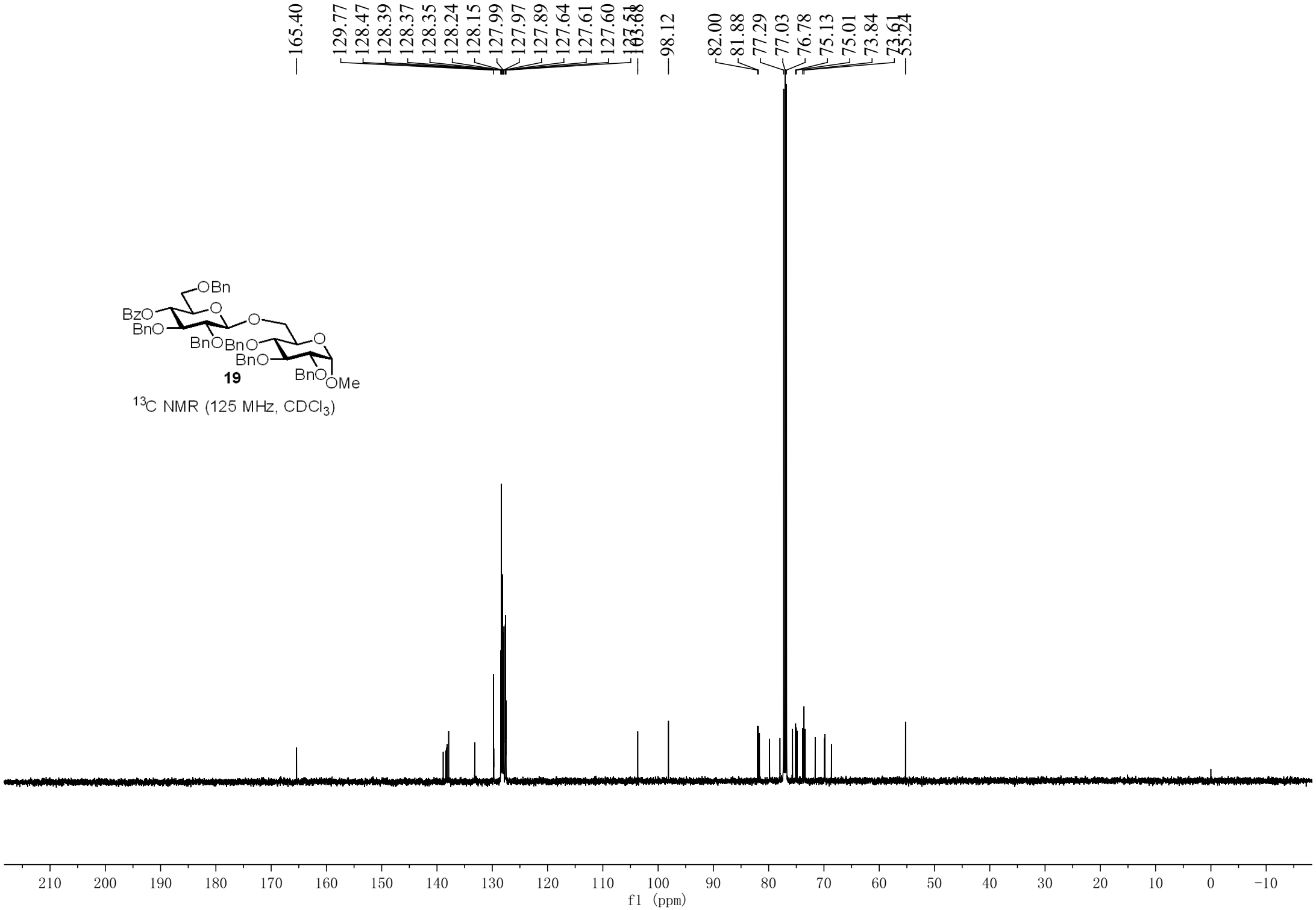
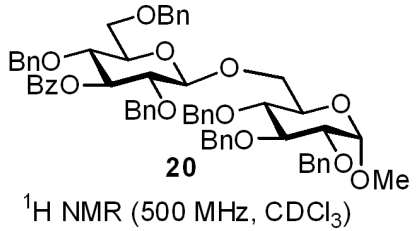
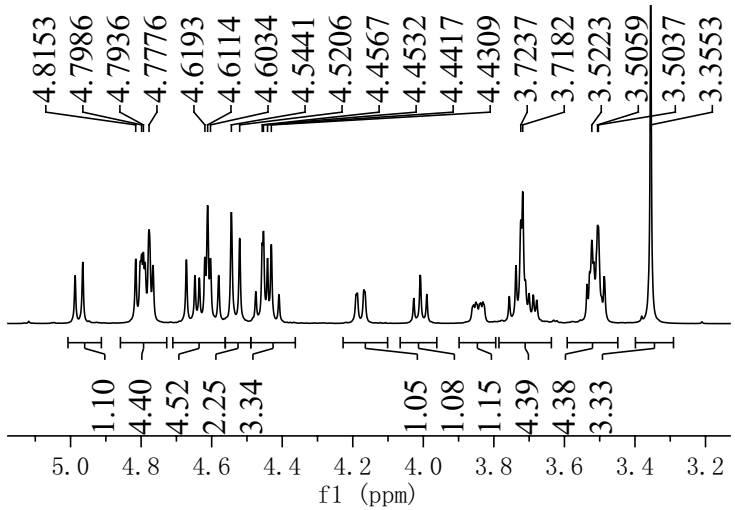
1.00
1.96
5.18
3.12
0.99
2.93
0.99
0.98
0.98
2.07
1.07
2.98
2.06
f1 (ppm)
2.00
1.03
2.28
16.06
10.24
5.48
3.04
f1 (ppm)

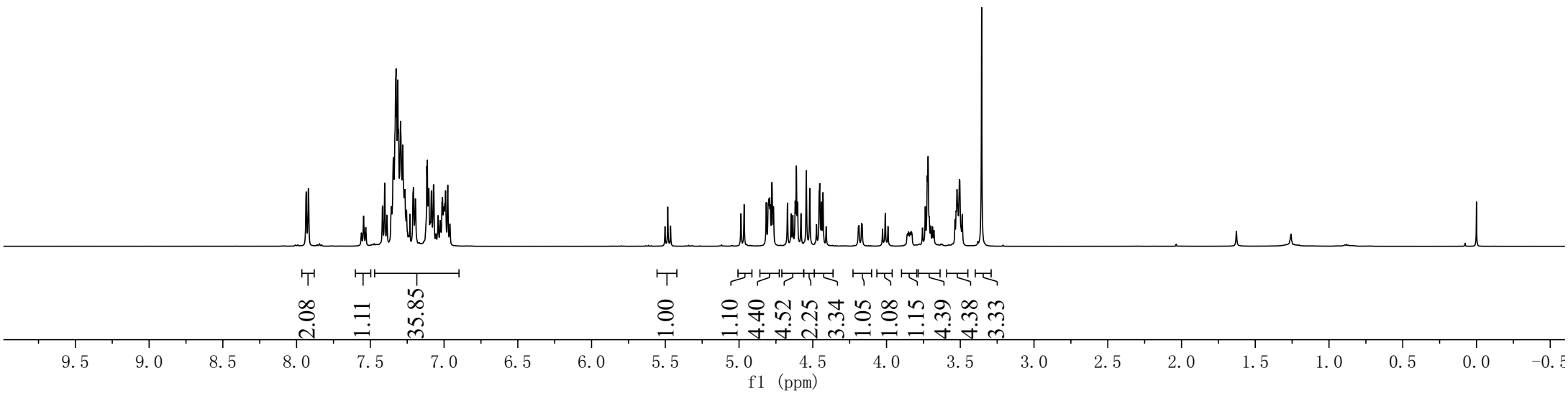

165.40
129.77
128.47
128.39
128.37
128.35
128.24
128.15
127.99
127.97
127.89
127.64
127.61
127.60
98.12
82.00
81.88
77.29
77.03
76.78
75.13
75.01
73.84
55.24
OBn
BzO
BnO
BnO
BnO
BnO
BnO
OMe
19
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)

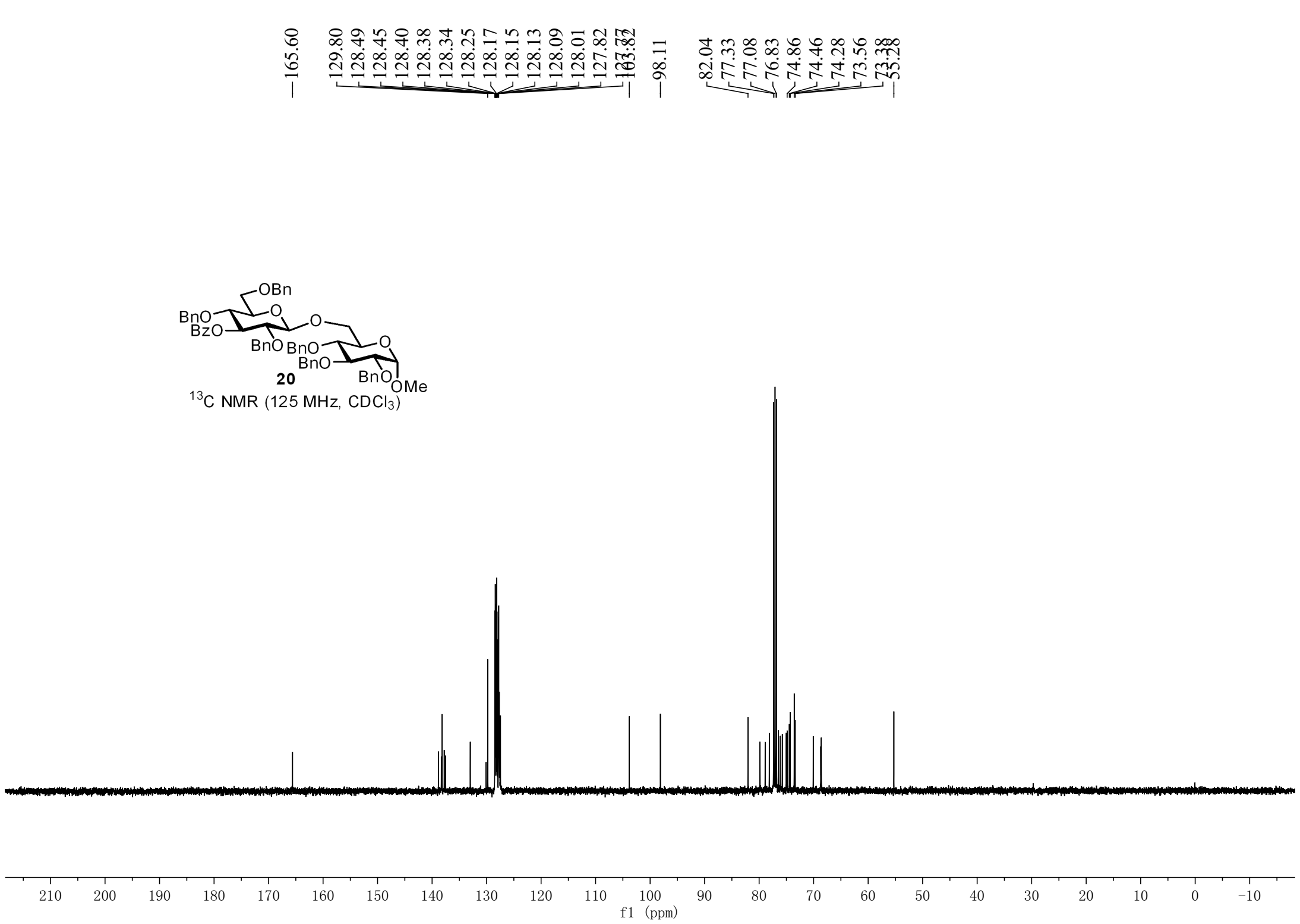


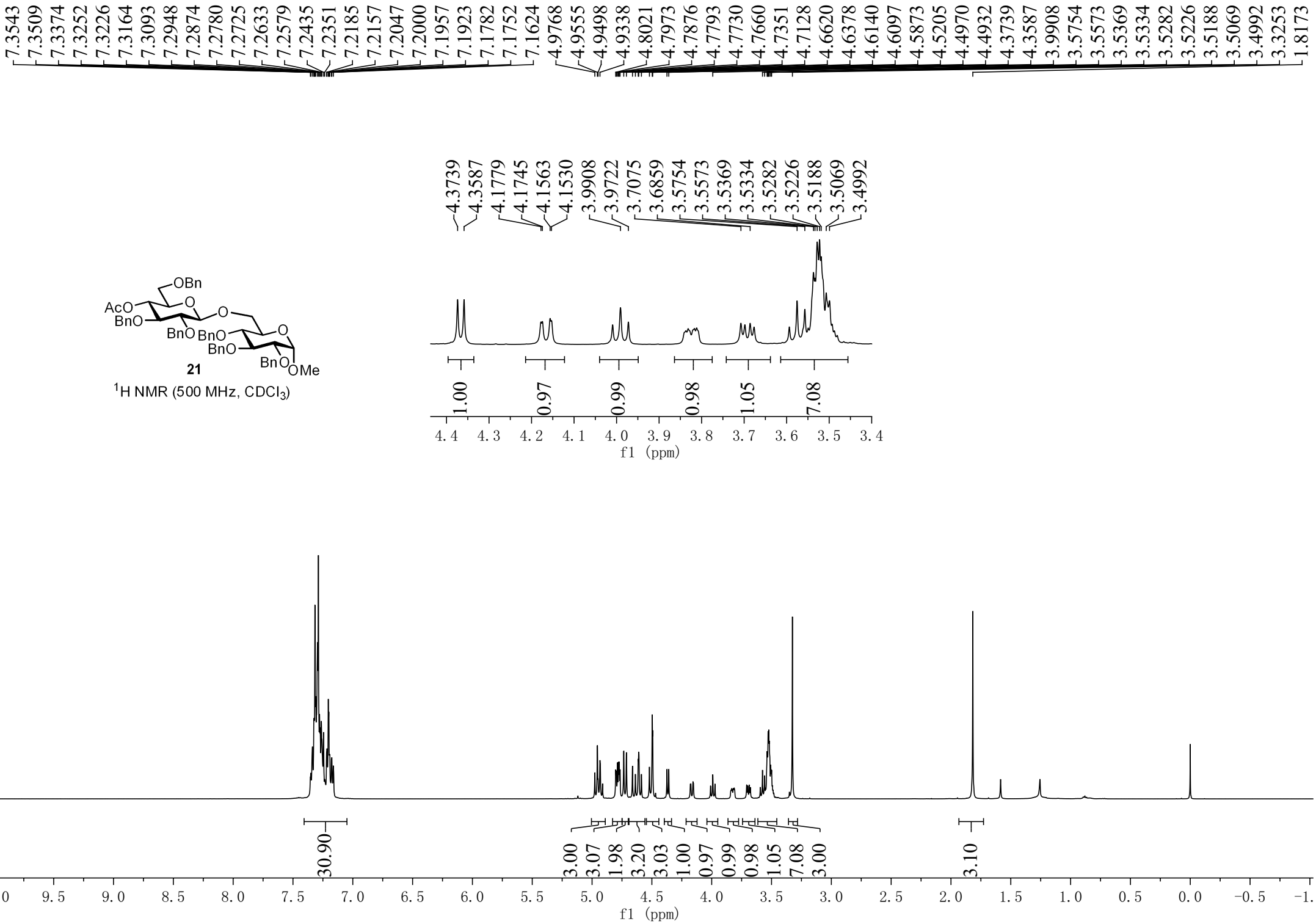

**20**

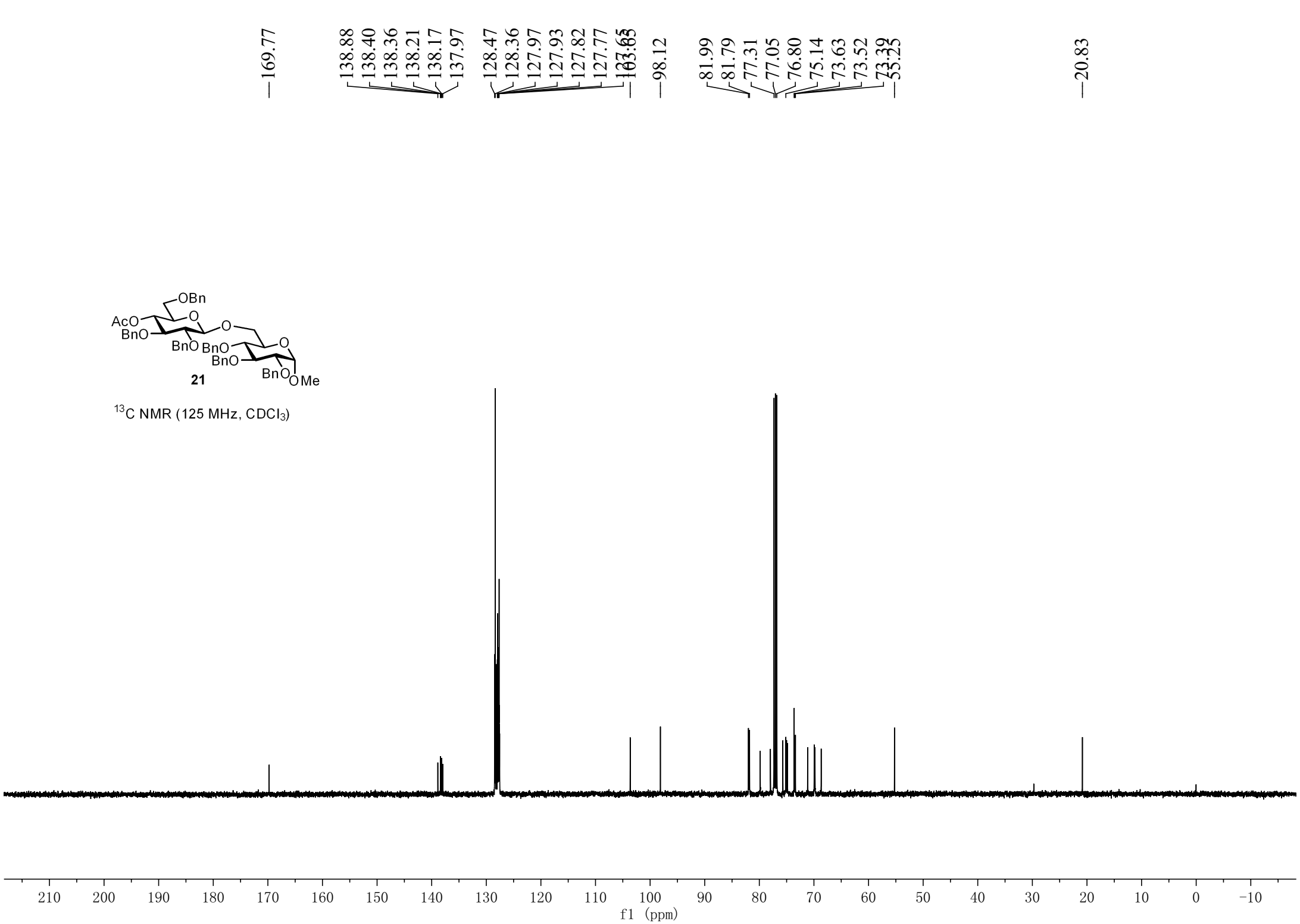
$^1$H NMR (500 MHz, $CDCl_3$)

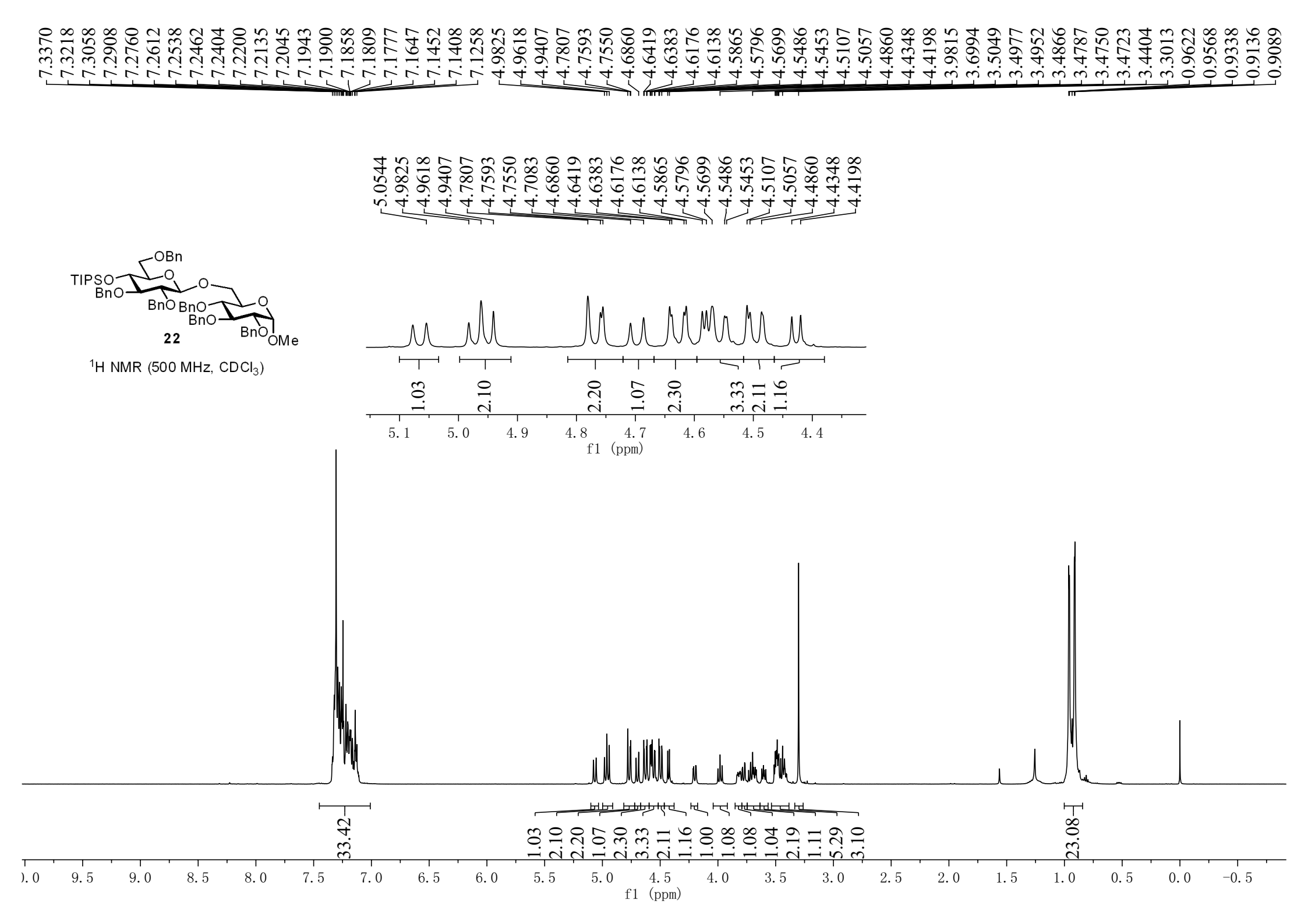


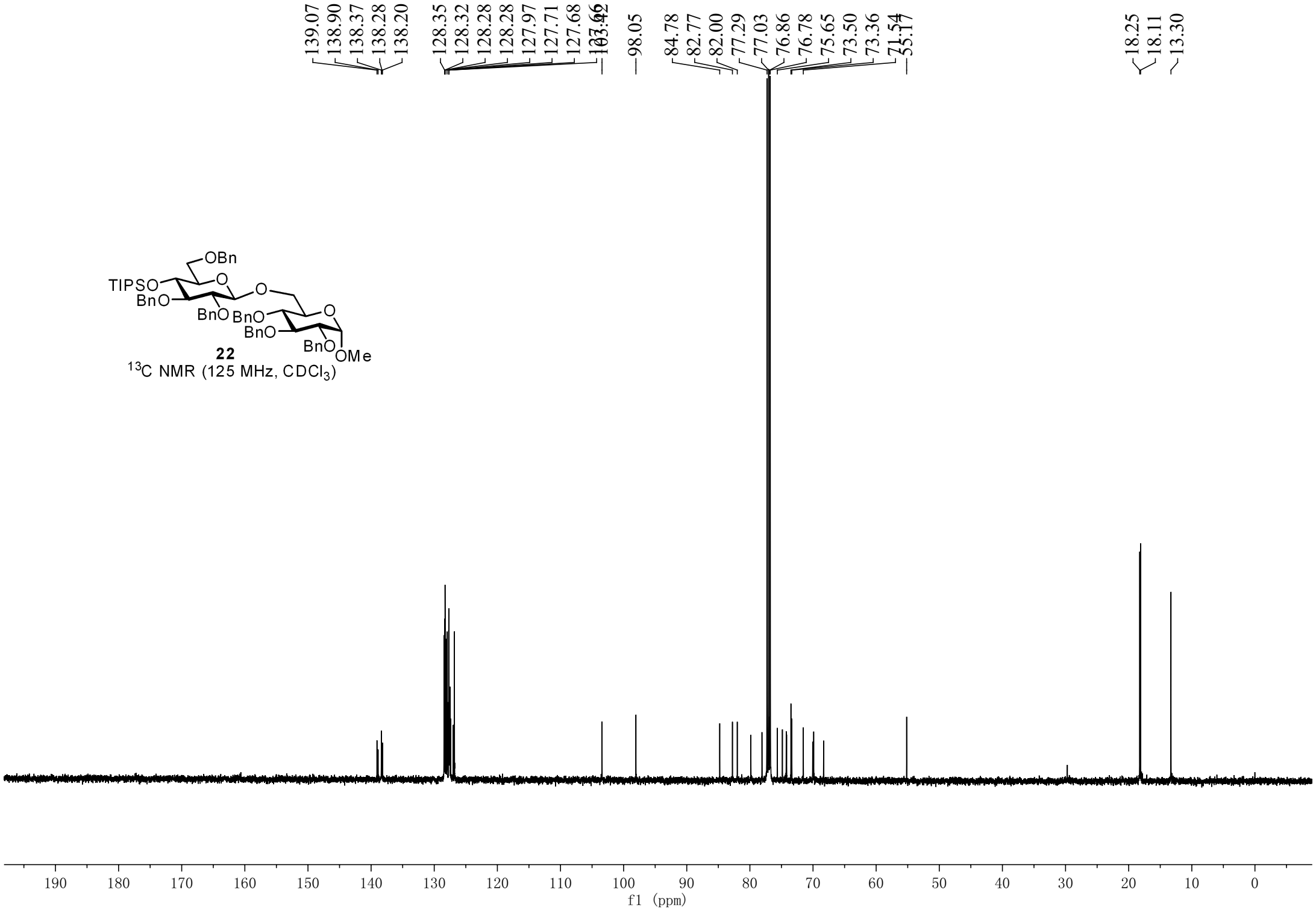



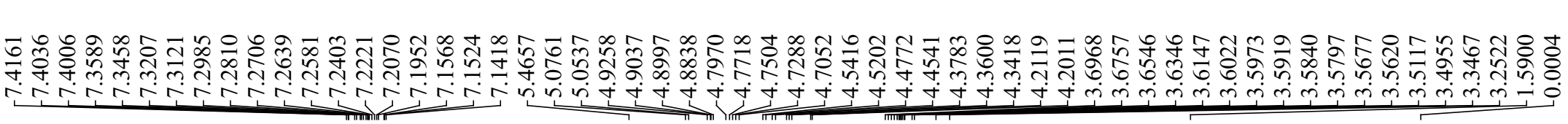

165.60
129.80
128.49
128.45
128.40
128.38
128.34
128.25
128.17
128.15
128.13
128.09
128.01
127.82
98.11
82.04
77.33
77.08
76.83
74.86
74.46
74.28
73.56
55.28
OBn
BnO
BzO
BnO
BnO
BnO
BnO
OMe
20
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

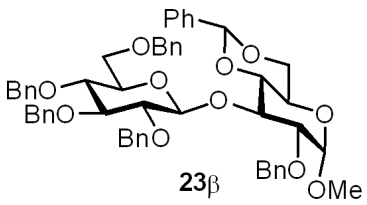

7.3543 7.3509 7.3374 7.3252 7.3226 7.3164 7.3093 7.2948 7.2874 7.2780 7.2725 7.2633 7.2579 7.2435 7.2351 7.2185 7.2157 7.2047 7.2000 7.1957 7.1923 7.1782 7.1752 7.1624
4.9768 4.9555 4.9498 4.9338 4.8021 4.7973 4.7876 4.7793 4.7730 4.7660 4.7351 4.7128 4.6620 4.6378 4.6140 4.6097 4.5873 4.5205 4.4970 4.4932 4.3739 4.3587 4.3253 1.8173
4.3739 4.3587 4.1779 4.1745 4.1563 4.1530 3.9908 3.9722 3.7075 3.6859 3.5754 3.5573 3.5369 3.5334 3.5282 3.5226 3.5188 3.5069 3.4992
OBn
AcO
BnO
BnO
BnO
BnO
BnO
BnO
OMe
21
1H NMR (500 MHz, CDCl3)
1.00 0.97 0.99 0.98 1.05 7.08
4.4 4.3 4.2 4.1 4.0 3.9 3.8 3.7 3.6 3.5 3.4
f1 (ppm)
30.90 3.00 3.07 1.98 3.20 3.03 1.00 0.97 0.99 0.98 1.05 7.08 3.00 3.10
0.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5 −1.
f1 (ppm)


169.77
138.88
138.40
138.36
138.21
138.17
137.97
128.47
128.36
127.97
127.93
127.82
127.77
103.65
98.12
81.99
81.79
77.31
77.05
76.80
75.14
73.63
73.52
73.39
55.25
20.83
OBn
AcO
BnO
BnO
BnO
BnO
BnO
OMe
21
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


7.3370
7.3218
7.3058
7.2908
7.2760
7.2612
7.2538
7.2462
7.2404
7.2200
7.2135
7.2045
7.1943
7.1900
7.1858
7.1809
7.1777
7.1647
7.1452
7.1408
7.1258
4.9825
4.9618
4.9407
4.7807
4.7593
4.7550
4.6860
4.6419
4.6383
4.6176
4.6138
4.5865
4.5796
4.5699
4.5486
4.5453
4.5107
4.5057
4.4860
4.4348
4.4198
3.9815
3.6994
3.5049
3.4977
3.4952
3.4866
3.4787
3.4750
3.4723
3.4404
3.3013
0.9622
0.9568
0.9338
0.9136
0.9089
5.0544
4.9825
4.9618
4.9407
4.7807
4.7593
4.7550
4.7083
4.6860
4.6419
4.6383
4.6176
4.6138
4.5865
4.5796
4.5699
4.5486
4.5453
4.5107
4.5057
4.4860
4.4348
4.4198
OBn
TIPSO
BnO
BnO
BnO
BnO
BnO
BnO
OMe
22
1H NMR (500 MHz, CDCl3)
1.03
2.10
2.20
1.07
2.30
3.33
2.11
1.16
5.1
5.0
4.9
4.8
4.7
4.6
4.5
4.4
f1 (ppm)
33.42
1.03
2.10
2.20
1.07
2.30
3.33
2.11
1.16
1.00
1.08
1.08
1.04
2.19
1.11
5.29
3.10
23.08
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
f1 (ppm)

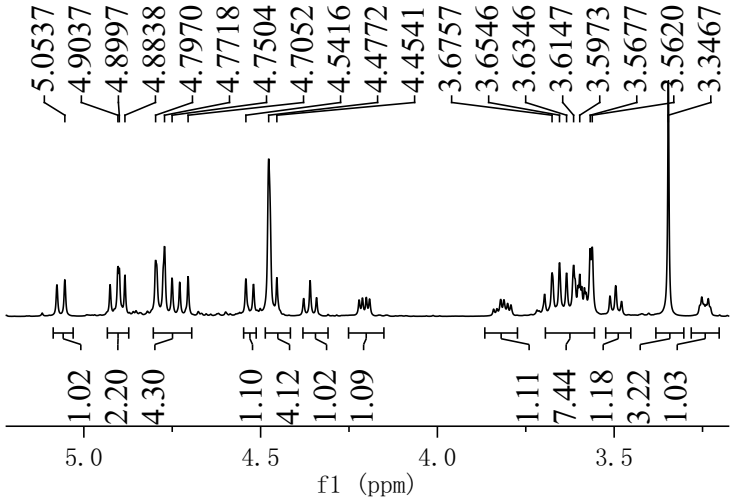

139.07
138.90
138.37
138.28
138.20
128.35
128.32
128.28
128.28
127.97
127.71
127.68
98.05
84.78
82.77
82.00
77.29
77.03
76.86
76.78
75.65
73.50
73.36
71.54
55.17
18.25
18.11
13.30
OBn
TIPSO
BnO
BnO
BnO
BnO
BnO
OMe
22
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

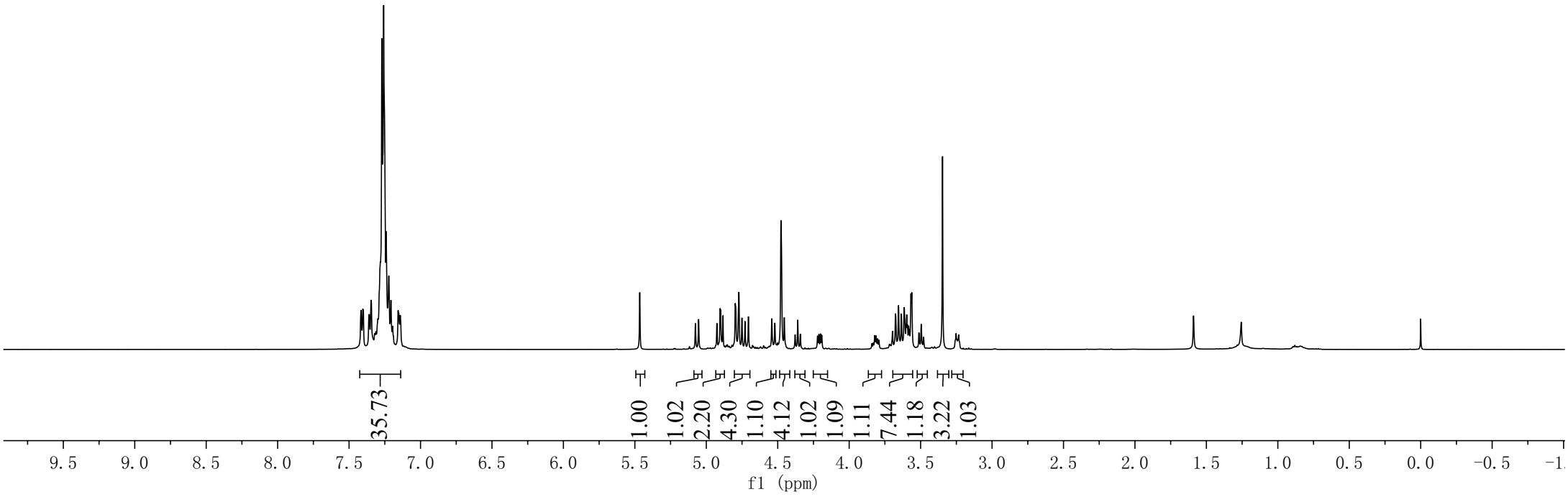


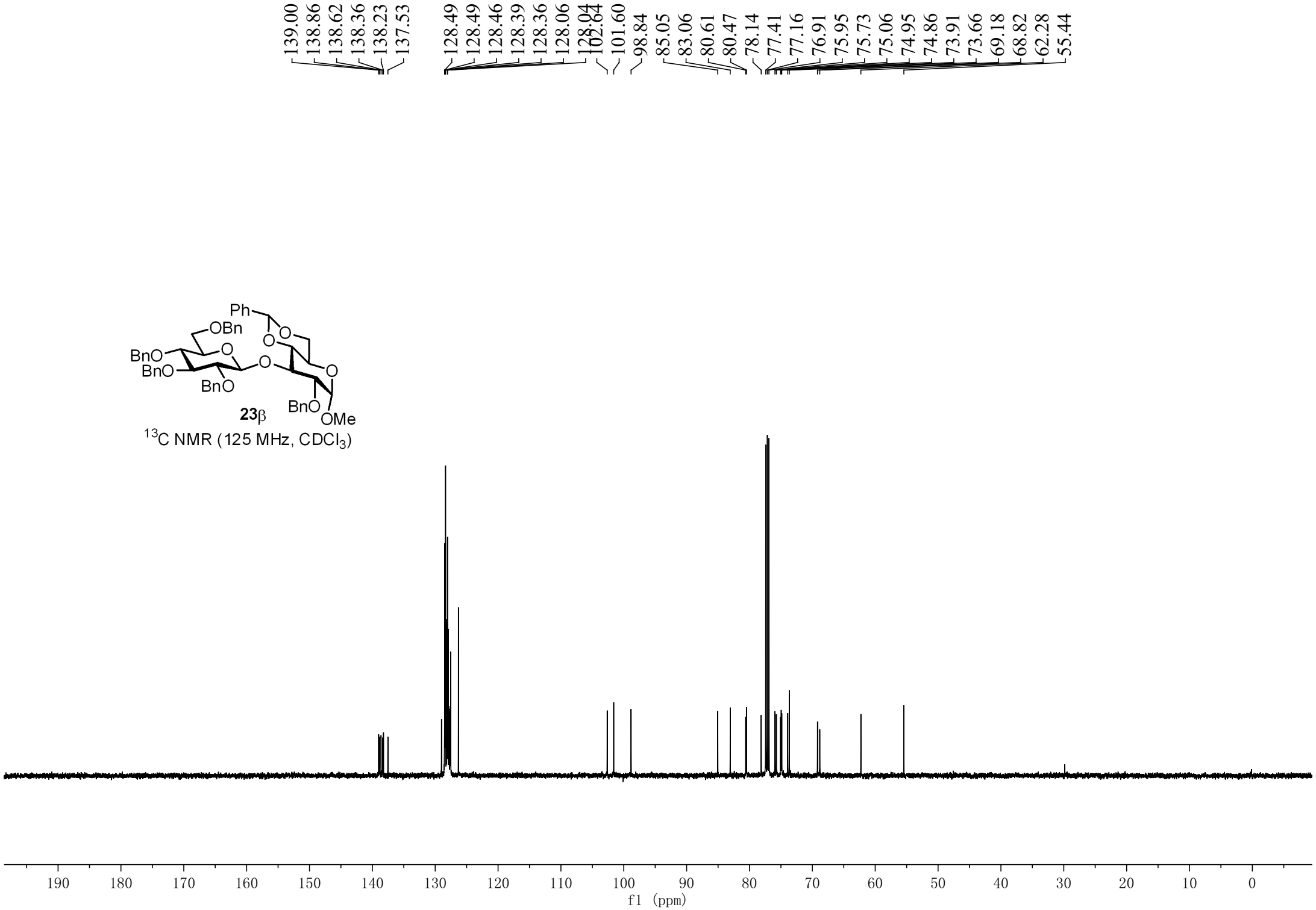



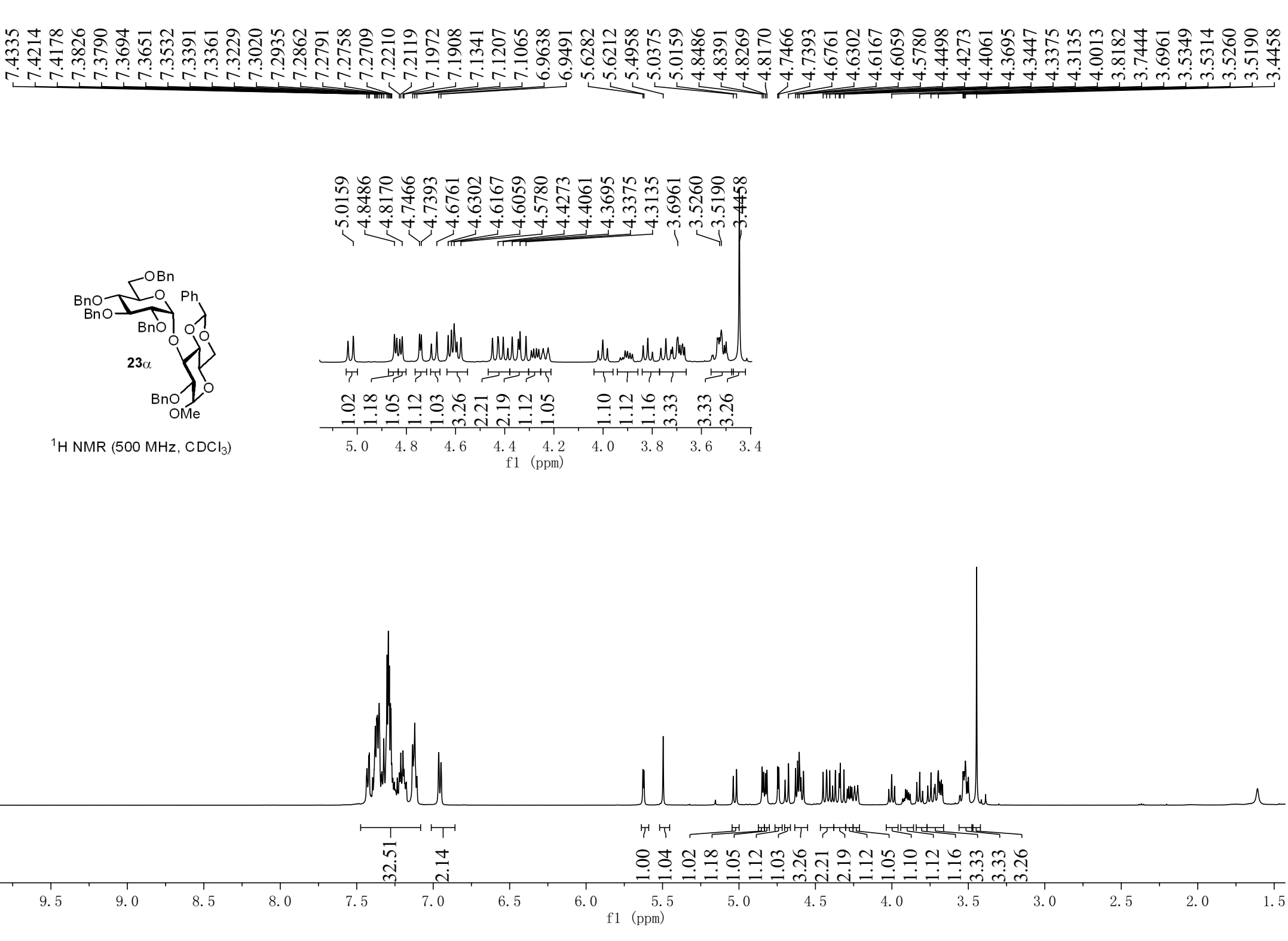

**23**β

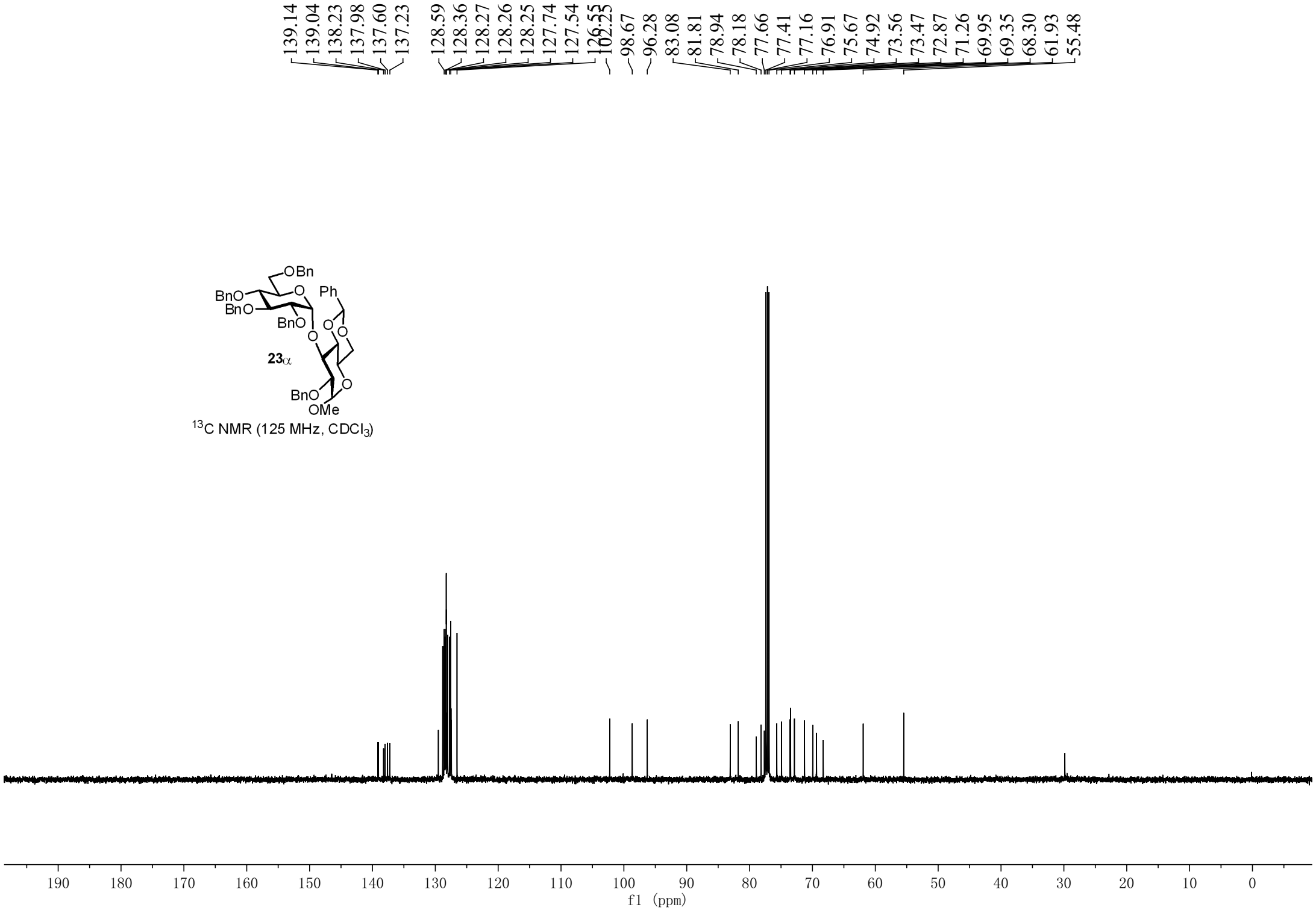
$^1$H NMR (500 MHz, $CDCl_3$)

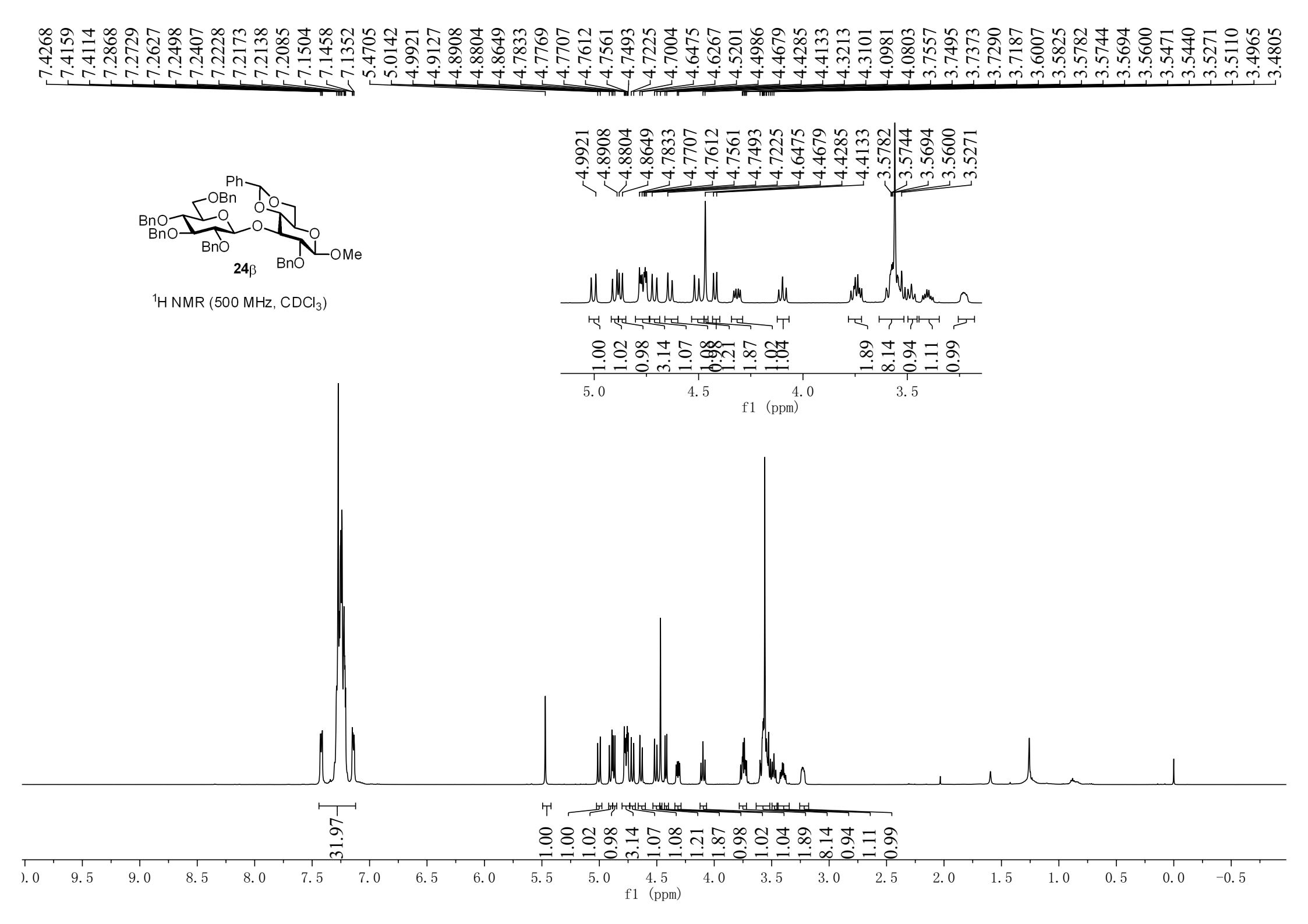


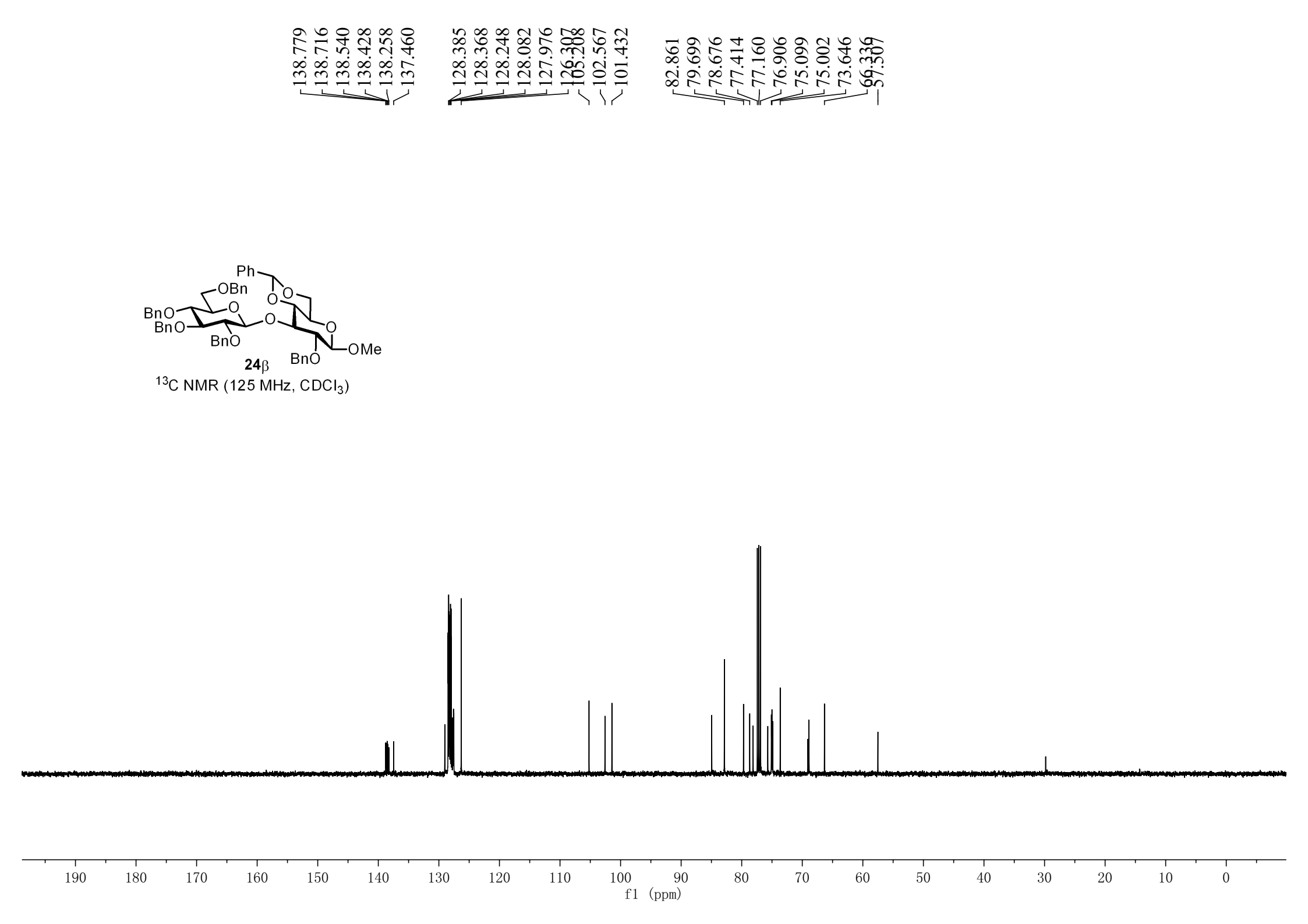



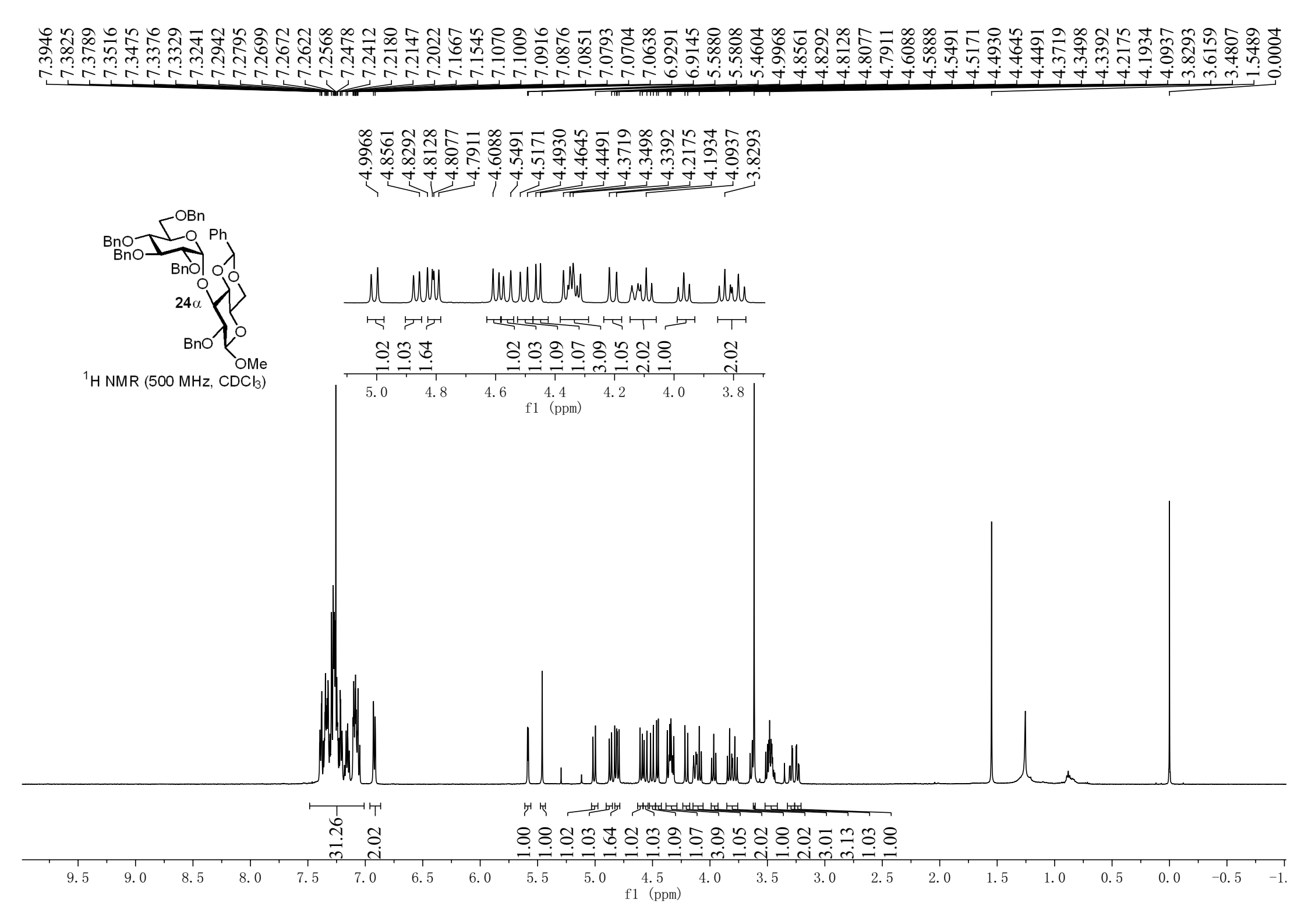

139.00
138.86
138.62
138.36
138.23
137.53
128.49
128.49
128.46
128.39
128.36
128.06
128.04
102.64
101.60
98.84
85.05
83.06
80.61
80.47
78.14
77.41
77.16
76.91
75.95
75.73
75.06
74.95
74.86
73.91
73.66
69.18
68.82
62.28
55.44
Ph
OBn
O
O
BnO
BnO
O
O
O
BnO
BnO
OMe
23β
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

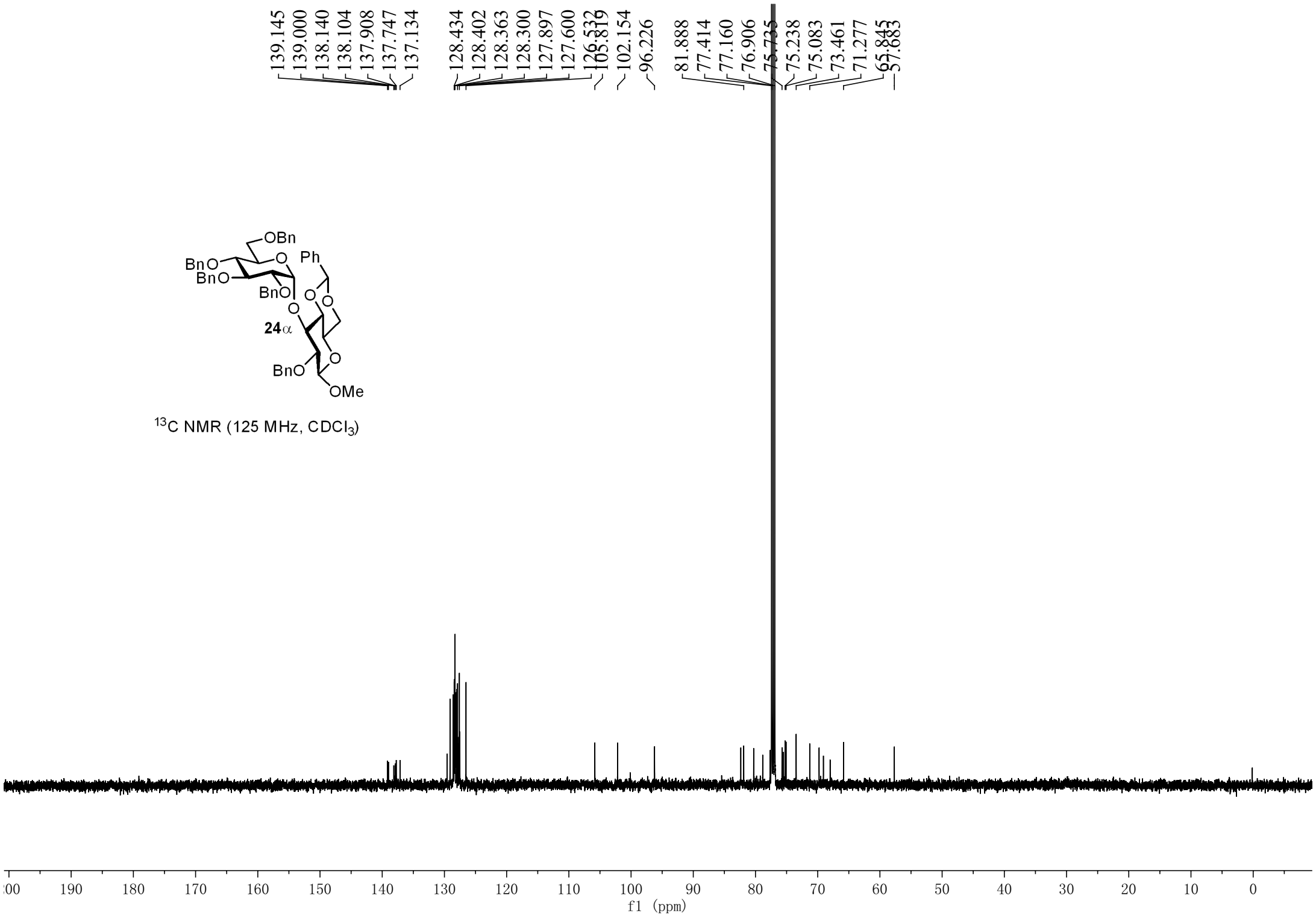

7.4335
7.4214
7.4178
7.3826
7.3790
7.3694
7.3651
7.3532
7.3391
7.3361
7.3229
7.3020
7.2935
7.2862
7.2791
7.2758
7.2709
7.2210
7.2119
7.1972
7.1908
7.1341
7.1207
7.1065
6.9638
6.9491
5.6282
5.6212
5.4958
5.0375
5.0159
4.8486
4.8391
4.8269
4.8170
4.7466
4.7393
4.6761
4.6302
4.6167
4.6059
4.5780
4.4498
4.4273
4.4061
4.3695
4.3447
4.3375
4.3135
4.0013
3.8182
3.7444
3.6961
3.5349
3.5314
3.5260
3.5190
3.4458
OBn
BnO
BnO
BnO
O
Ph
O
O
O
23α
BnO
OMe
O
1H NMR (500 MHz, CDCl3)
1.02
1.18
1.05
1.12
1.03
3.26
2.21
2.19
1.12
1.05
1.10
1.12
1.16
3.33
3.33
3.26
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
f1 (ppm)
32.51
2.14
1.00
1.04
1.02
1.18
1.05
1.12
1.03
3.26
2.21
2.19
1.12
1.05
1.10
1.12
1.16
3.33
3.33
3.26
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
f1 (ppm)

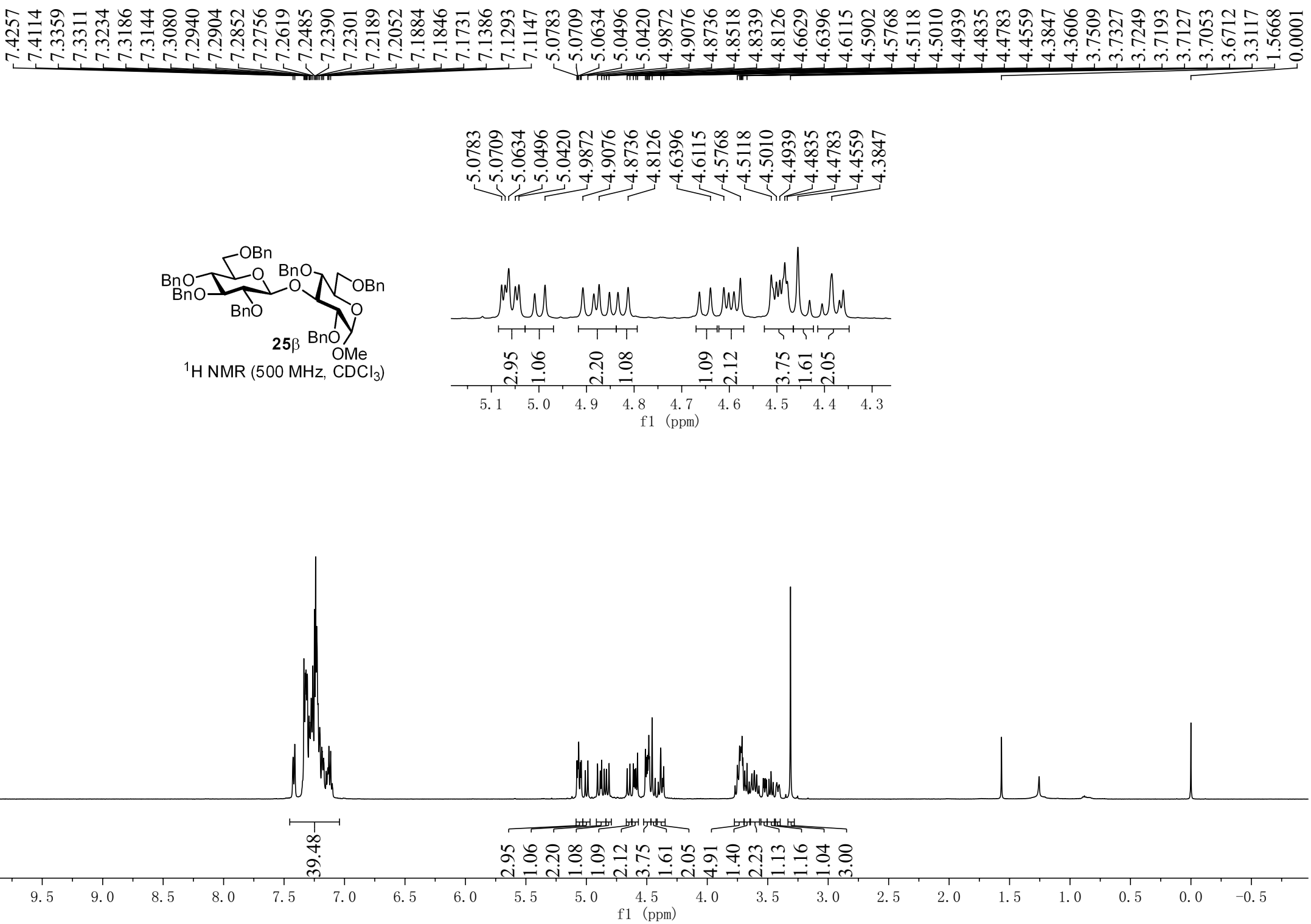

139.14
139.04
138.23
137.98
137.60
137.23
128.59
128.36
128.27
128.26
128.25
127.74
127.54
126.55
102.25
98.67
96.28
83.08
81.81
78.94
78.18
77.66
77.41
77.16
76.91
75.67
74.92
73.56
73.47
72.87
71.26
69.95
69.35
68.30
61.93
55.48
OBn
BnO
BnO
BnO
O
Ph
O
O
O
O
BnO
OMe
23α
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

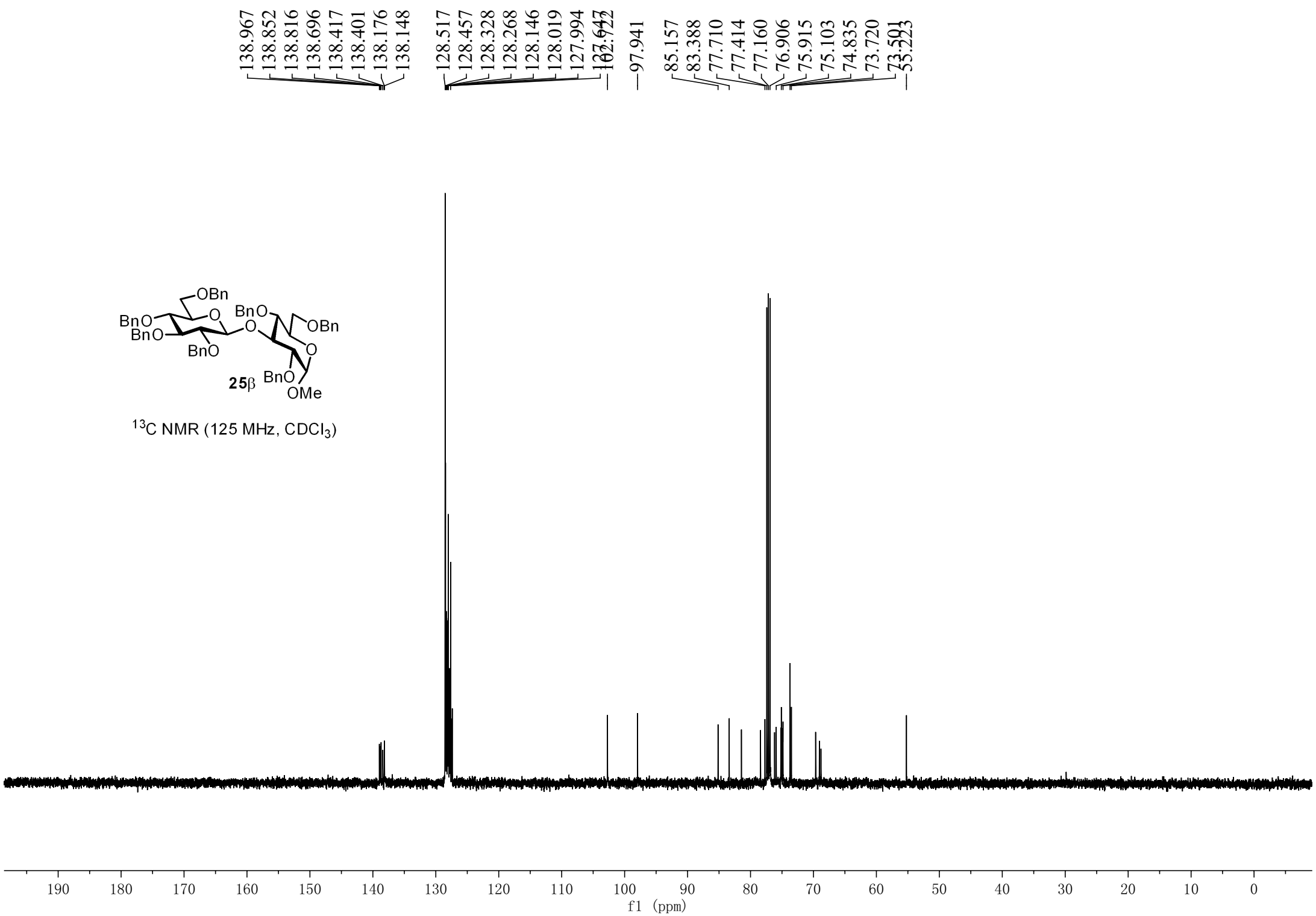

7.4268
7.4159
7.4114
7.2868
7.2729
7.2627
7.2498
7.2407
7.2228
7.2173
7.2138
7.2085
7.1504
7.1458
7.1352
5.4705
5.0142
4.9921
4.9127
4.8908
4.8804
4.8649
4.7833
4.7769
4.7707
4.7612
4.7561
4.7493
4.7225
4.7004
4.6475
4.6267
4.5201
4.4986
4.4679
4.4285
4.4133
4.3213
4.3101
4.0981
4.0803
3.7557
3.7495
3.7373
3.7290
3.7187
3.6007
3.5825
3.5782
3.5744
3.5694
3.5600
3.5471
3.5440
3.5271
3.5110
3.4965
3.4805
Ph
OBn
BnO
BnO
BnO
BnO
OMe
24β
1H NMR (500 MHz, CDCl3)
4.9921
4.8908
4.8804
4.8649
4.7833
4.7707
4.7612
4.7561
4.7493
4.7225
4.6475
4.4679
4.4285
4.4133
3.5782
3.5744
3.5694
3.5600
3.5271
1.00
1.02
0.98
3.14
1.07
1.08
0.98
1.21
1.87
1.02
1.04
1.89
8.14
0.94
1.11
0.99
5.0
4.5
4.0
3.5
f1 (ppm)
31.97
1.00
1.00
1.02
0.98
3.14
1.07
1.08
1.21
1.87
0.98
1.02
1.04
1.89
8.14
0.94
1.11
0.99
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
f1 (ppm)

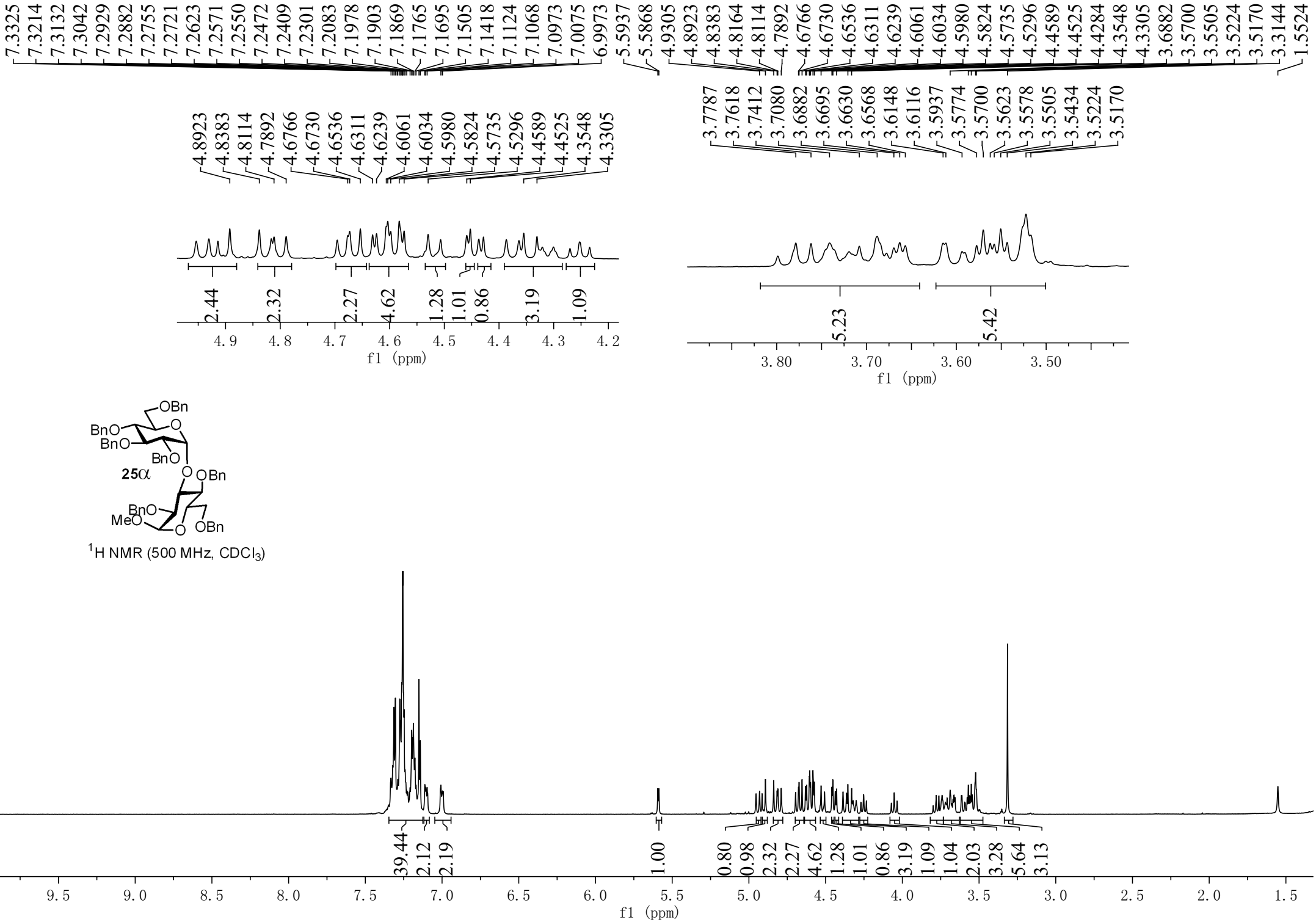

138.779
138.716
138.540
138.428
138.258
137.460
128.385
128.368
128.248
128.082
127.976
126.307
105.208
102.567
101.432
82.861
79.699
78.676
77.414
77.160
76.906
75.099
75.002
73.646
66.336
57.307
Ph
OBn
BnO
BnO
BnO
BnO
OMe
24β
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


OBn
BnO
BnO
BnO
O
Ph
O
O
O
24α
BnO
O
OMe
1H NMR (500 MHz, CDCl3)
f1 (ppm)
f1 (ppm)

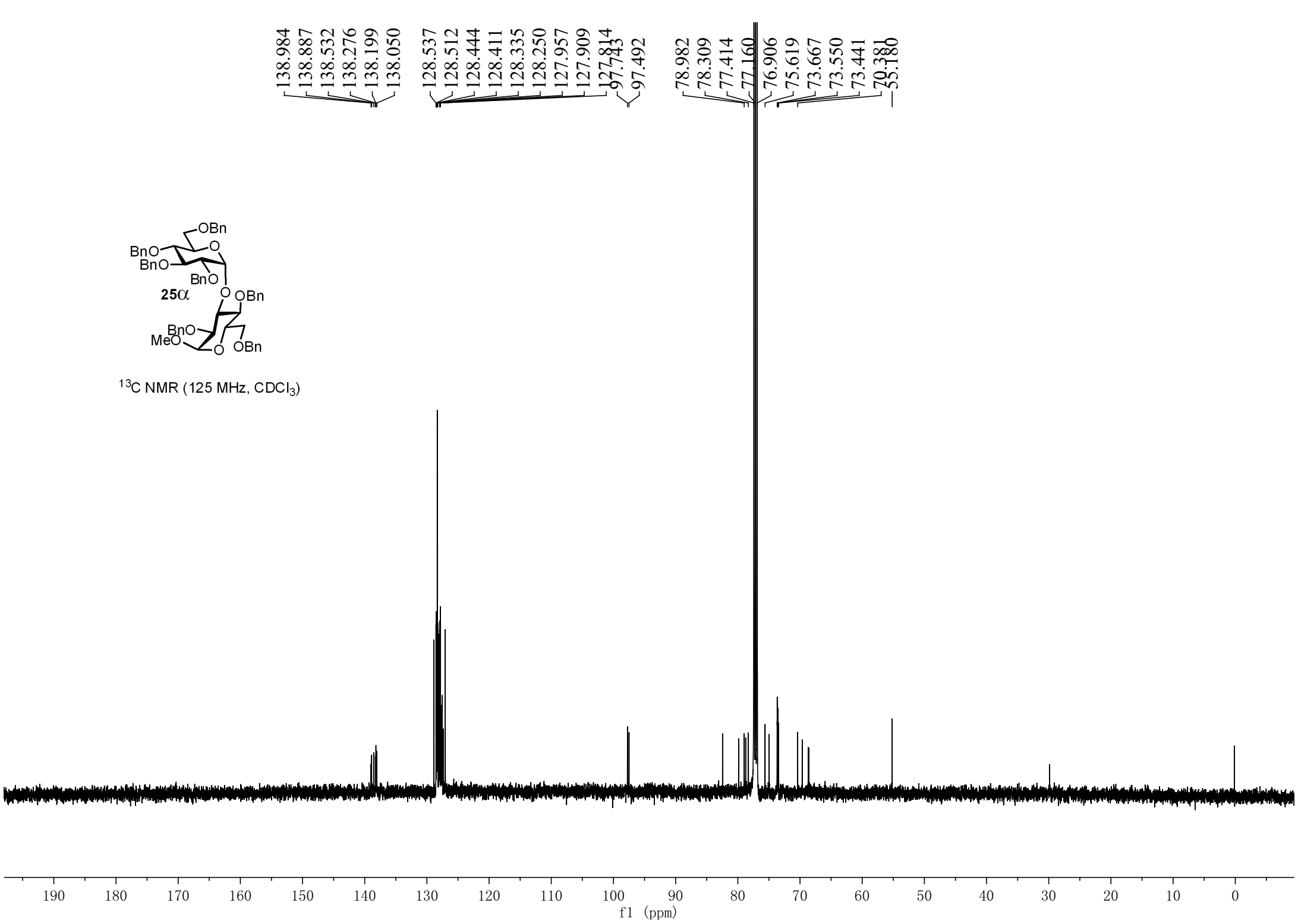

139.145
139.000
138.140
138.104
137.908
137.747
137.134
128.434
128.402
128.363
128.300
127.897
127.600
126.532
105.819
102.154
96.226
81.888
77.414
77.160
76.906
75.735
75.238
75.083
73.461
71.277
65.845
57.883
OBn
BnO
BnO
BnO
O
Ph
O
O
O
24α
O
BnO
OMe
13C NMR (125 MHz, CDCl3)
f1 (ppm)

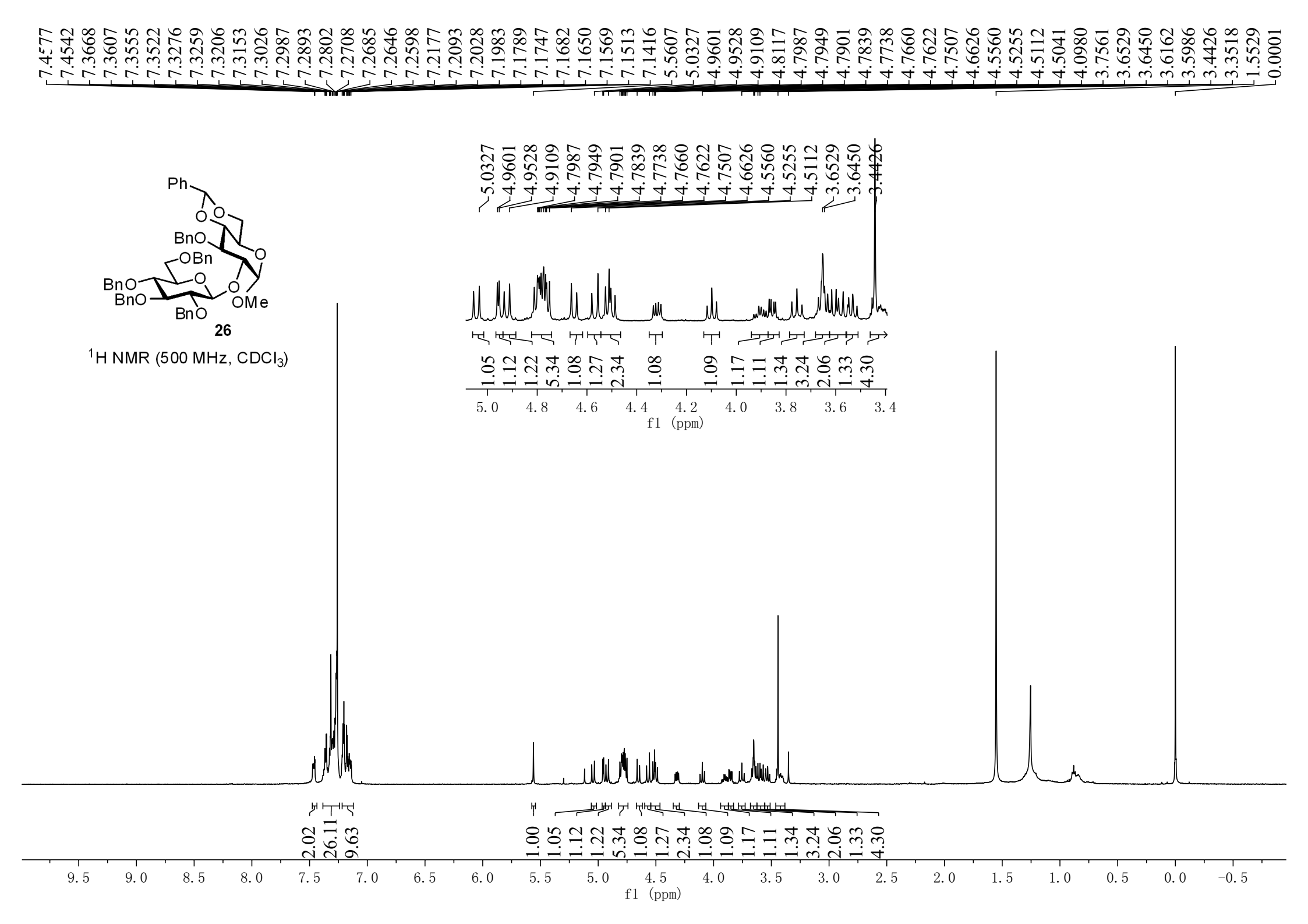

7.4257 7.4114 7.3359 7.3311 7.3234 7.3186 7.3144 7.3080 7.2940 7.2904 7.2852 7.2756 7.2619 7.2485 7.2390 7.2301 7.2189 7.2052 7.1884 7.1846 7.1731 7.1386 7.1293 7.1147
5.0783 5.0709 5.0634 5.0496 5.0420 4.9872 4.9076 4.8736 4.8518 4.8339 4.8126 4.6629 4.6396 4.6115 4.5902 4.5768 4.5118 4.5010 4.4939 4.4835 4.4783 4.4559 4.3847 4.3606 3.7509 3.7327 3.7249 3.7193 3.7127 3.7053 3.6712 3.3117 1.5668 0.0001
OBn
BnO
BnO
BnO
O
BnO
O
OBn
O
BnO
OMe
25β
1H NMR (500 MHz, CDCl3)
2.95 1.06 2.20 1.08 1.09 2.12 3.75 1.61 2.05
5.1 5.0 4.9 4.8 4.7 4.6 4.5 4.4 4.3
f1 (ppm)
39.48
2.95 1.06 2.20 1.08 1.09 2.12 3.75 1.61 2.05 4.91 1.40 2.23 1.13 1.16 1.04 3.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 −0.5
f1 (ppm)

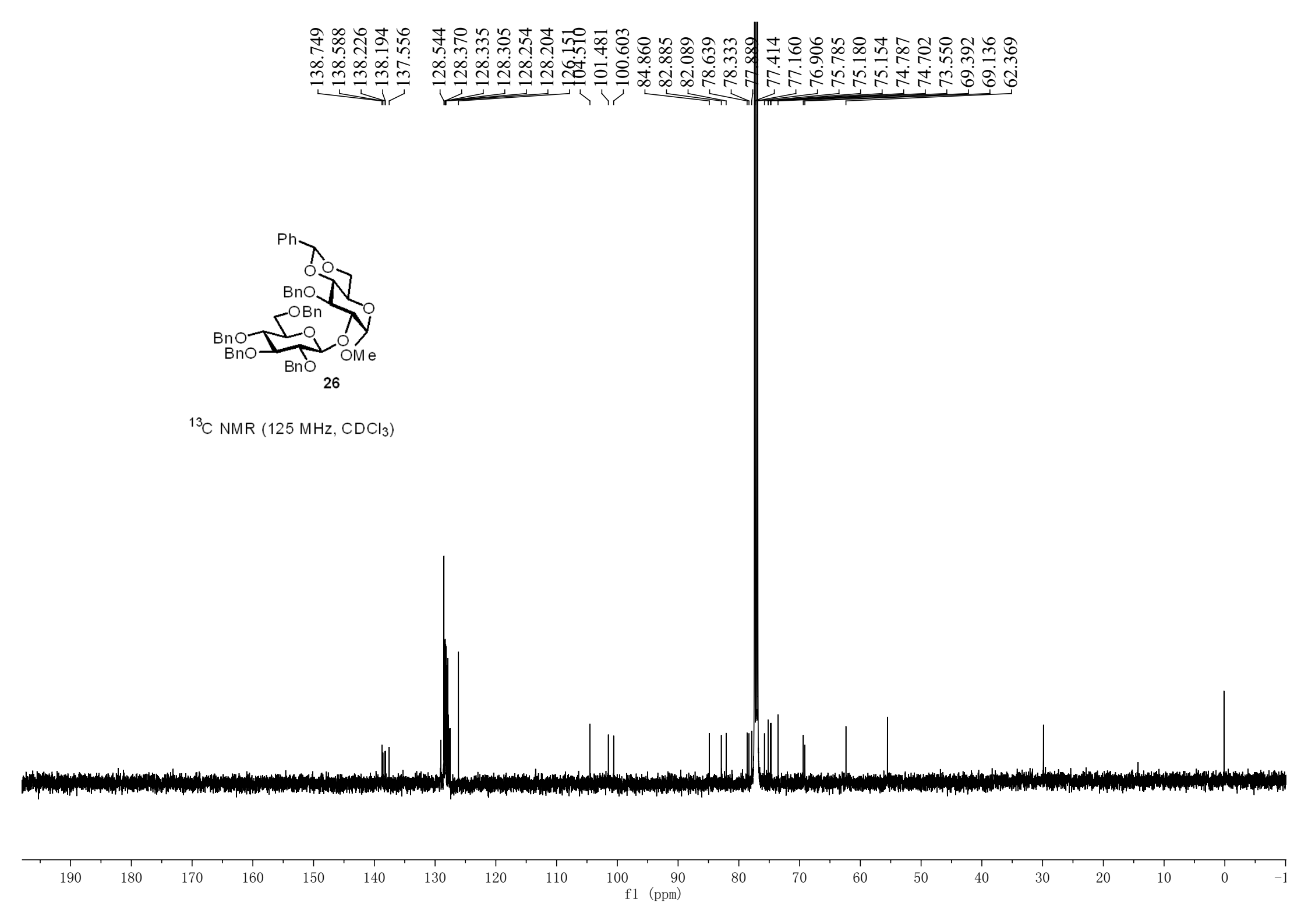

138.967
138.852
138.816
138.696
138.417
138.401
138.176
138.148
128.517
128.457
128.328
128.268
128.146
128.019
127.994
97.941
85.157
83.388
77.710
77.414
77.160
76.906
75.915
75.103
74.835
73.720
55.223
OBn
BnO
BnO
BnO
O
BnO
O
OBn
O
BnO
OMe
25β
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

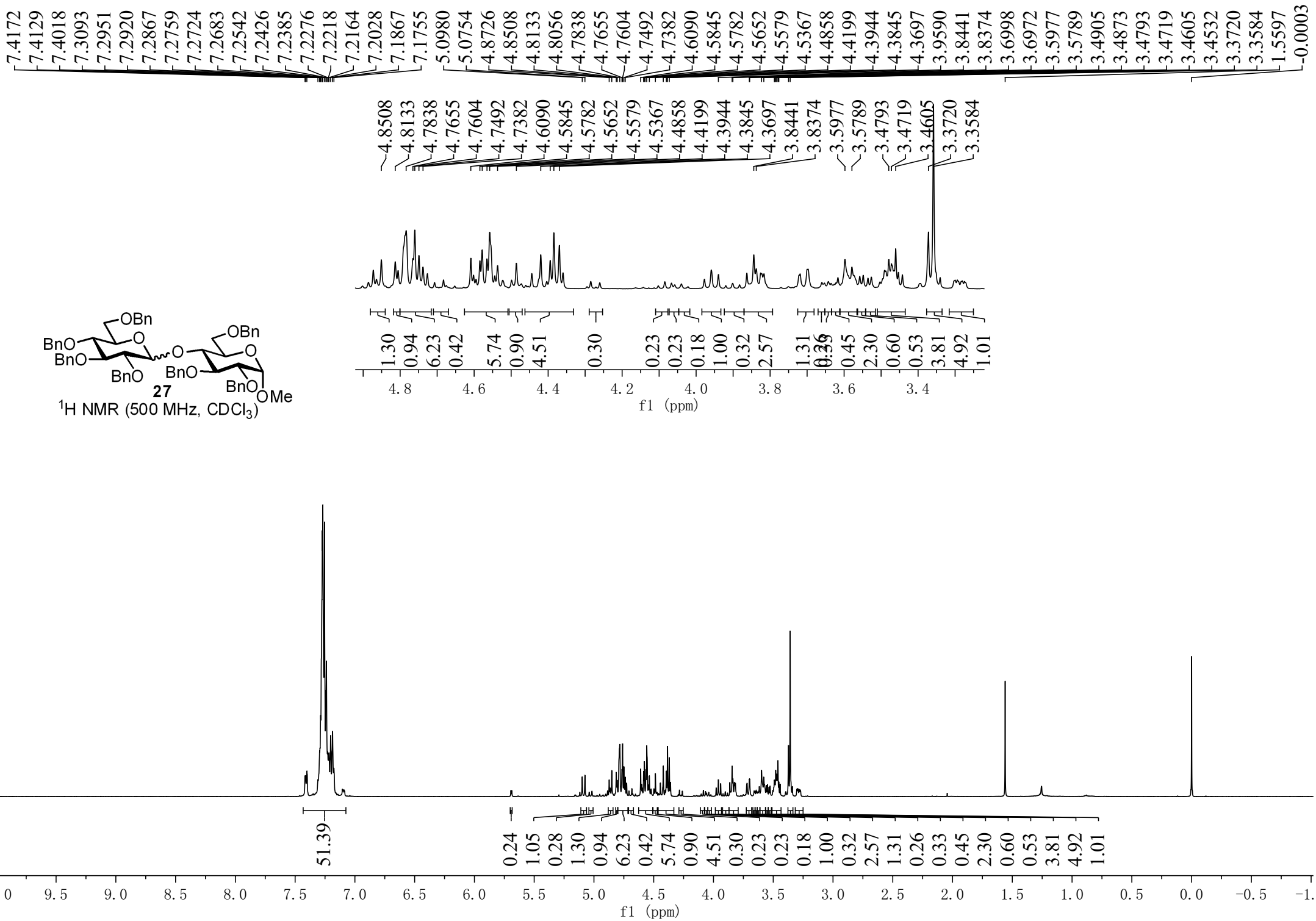


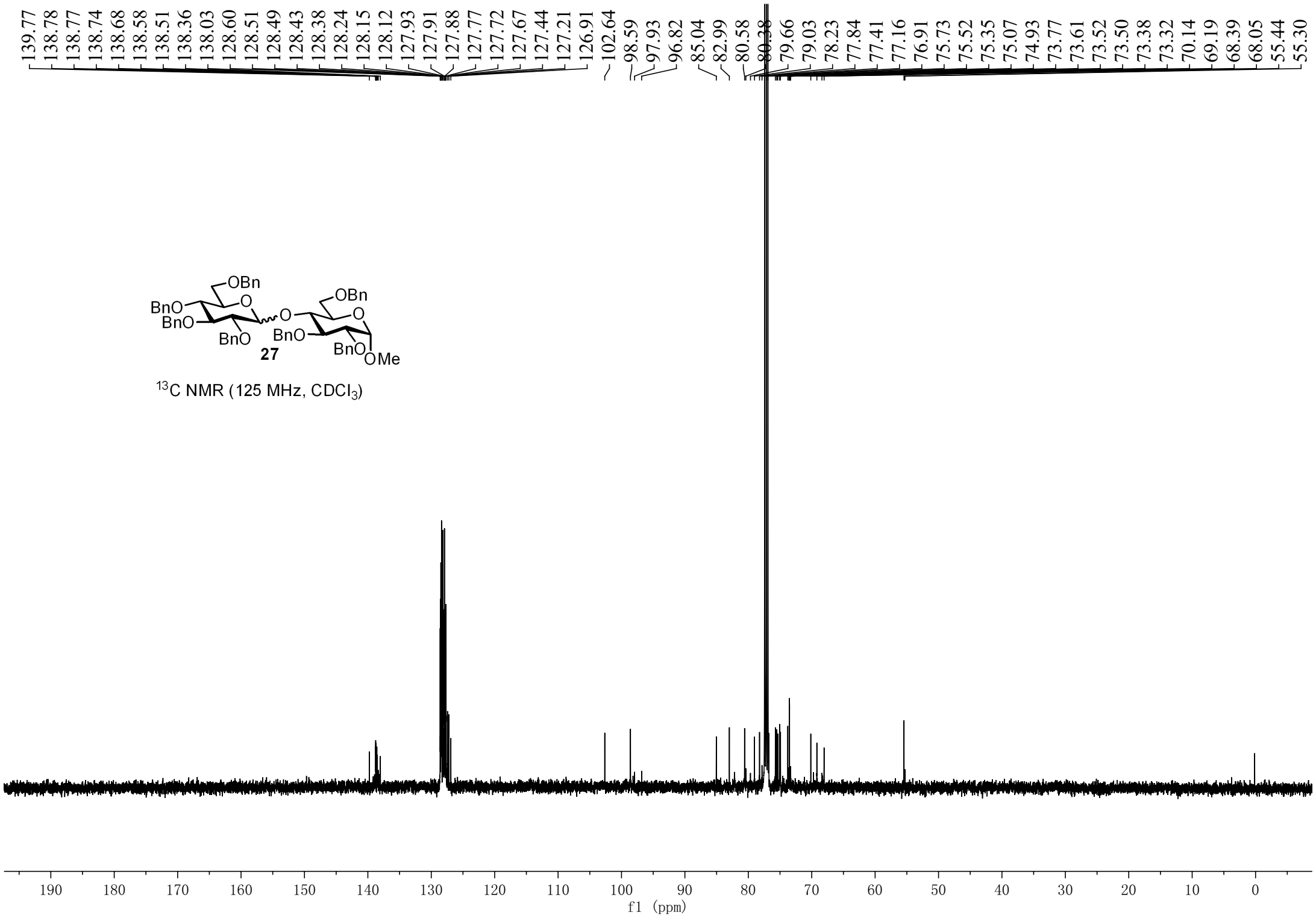

$^1$H NMR (500 MHz, $CDCl_3$)

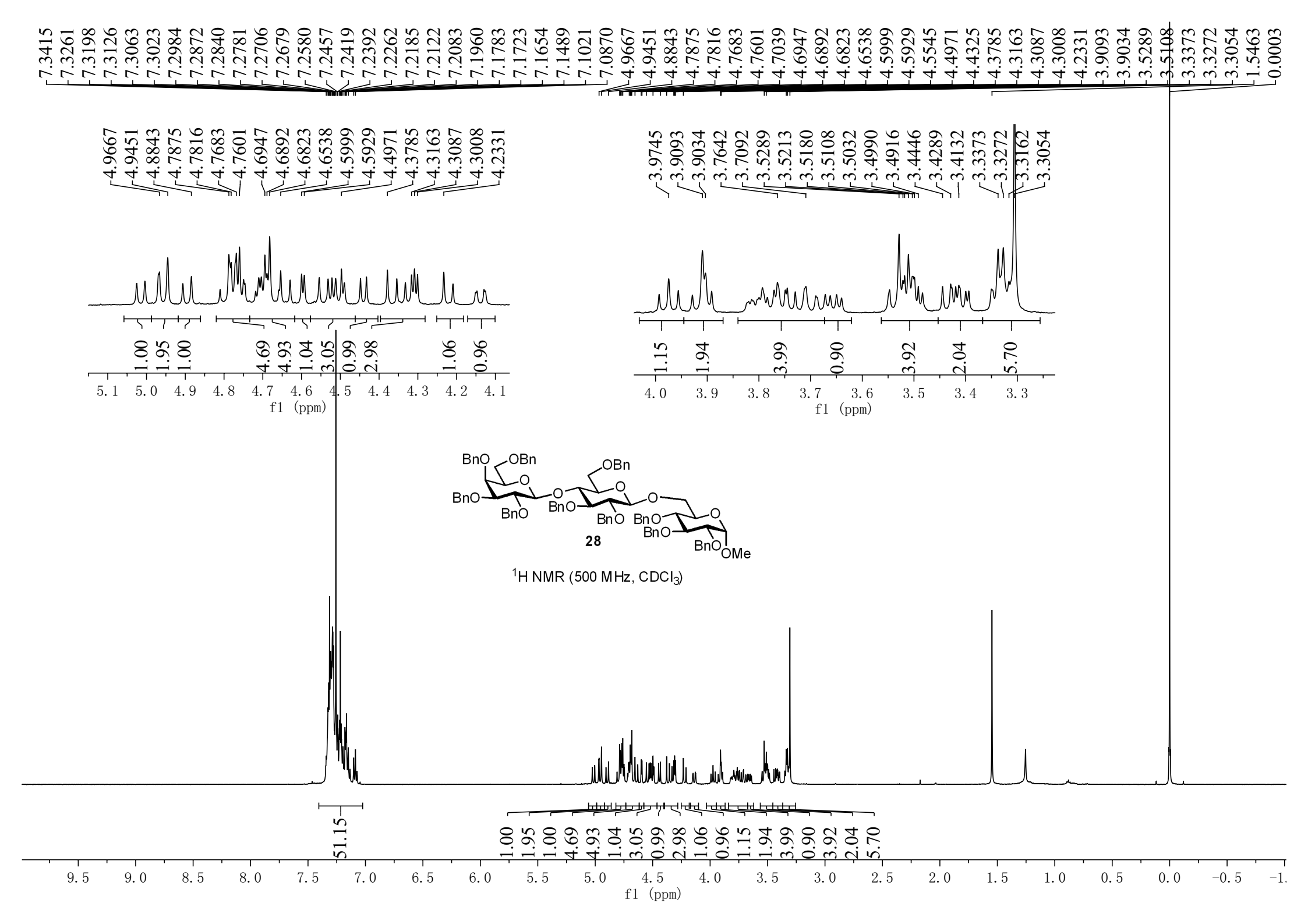

138.984
138.887
138.532
138.276
138.199
138.050
128.537
128.512
128.444
128.411
128.335
128.250
127.957
127.909
127.814
127.743
97.492
78.982
78.309
77.414
77.160
76.906
75.619
73.667
73.550
73.441
70.381
55.180
OBn
BnO
BnO
BnO
O
25α
O
OBn
BnO
MeO
O
OBn
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

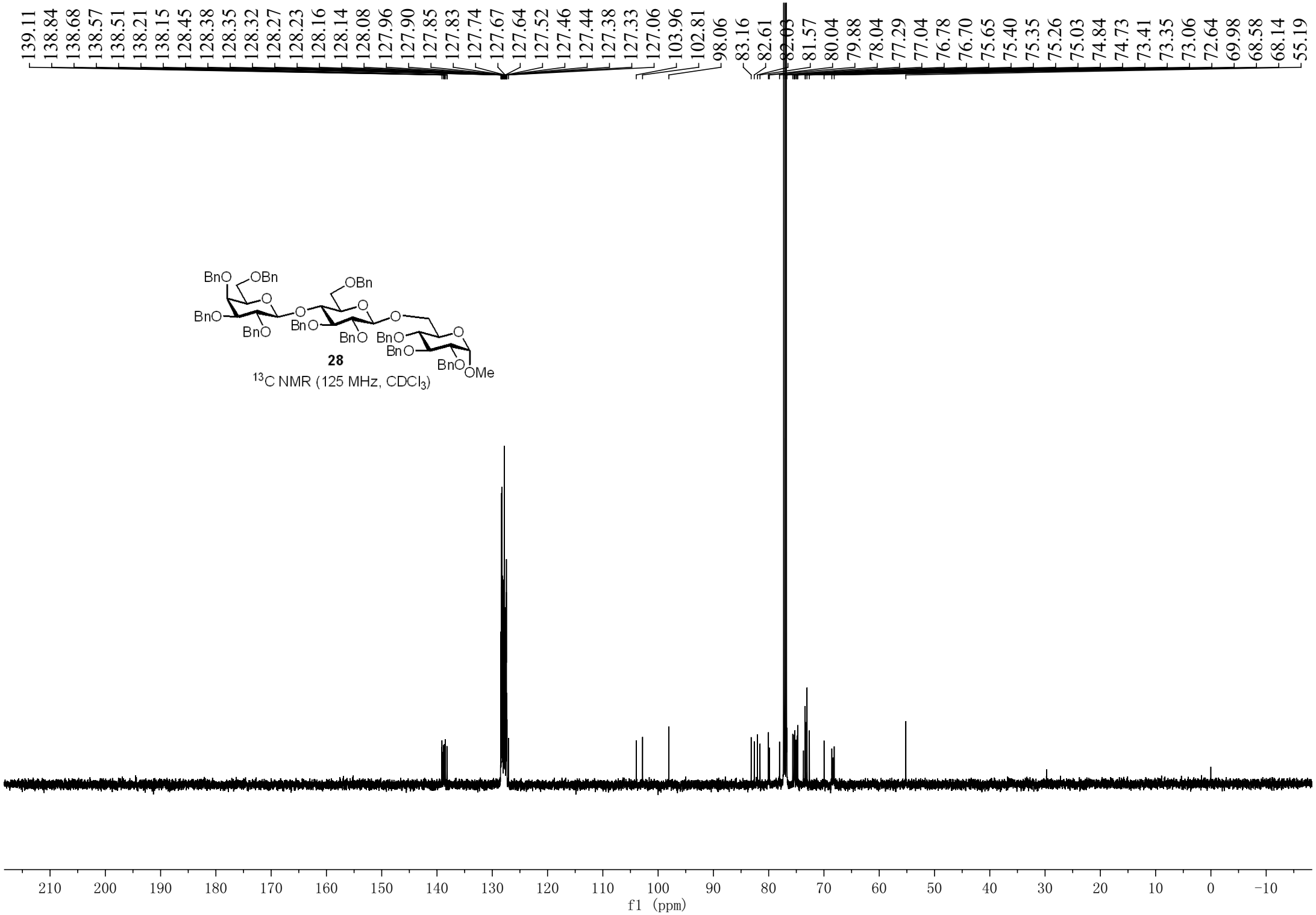

Ph
BnO
OBn
BnO
BnO
BnO
OMe
26
1H NMR (500 MHz, CDCl3)
f1 (ppm)

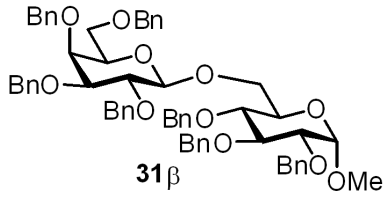

138.749
138.588
138.226
138.194
137.556
128.544
128.370
128.335
128.305
128.254
128.204
126.151
104.510
101.481
100.603
84.860
82.885
82.089
78.639
78.333
77.889
77.414
77.160
76.906
75.785
75.180
75.154
74.787
74.702
73.550
69.392
69.136
62.369
Ph
BnO
OBn
BnO
BnO
BnO
OMe
26
$^{13}$C NMR (125 MHz, $CDCl_3$)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)


7.4172 7.4129 7.4018 7.3093 7.2951 7.2920 7.2867 7.2759 7.2724 7.2683 7.2542 7.2426 7.2385 7.2276 7.2218 7.2164 7.2028 7.1867 7.1755
5.0980 5.0754 4.8726 4.8508 4.8133 4.8056 4.7838 4.7655 4.7604 4.7492 4.7382 4.6090 4.5845 4.5782 4.5652 4.5579 4.5367 4.4858 4.4199 4.3944 4.3845 4.3697 3.9590 3.8441 3.8374 3.6998 3.6972 3.5977 3.5789 3.4905 3.4873 3.4793 3.4719 3.4605 3.4532 3.3720 3.3584 1.5597 -0.0003
4.8508 4.8133 4.7838 4.7655 4.7604 4.7492 4.7382 4.6090 4.5845 4.5782 4.5652 4.5579 4.5367 4.4858 4.4199 4.3944 4.3845 4.3697 3.8441 3.8374 3.5977 3.5789 3.4793 3.4719 3.4605 3.3720 3.3584
1.30 0.94 6.23 0.42 5.74 0.90 4.51 0.30 0.23 0.23 0.18 1.00 0.32 2.57 1.31 0.45 2.30 0.60 0.53 3.81 4.92 1.01
4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4
f1 (ppm)
OBn
BnO
BnO
O
O
BnO
OBn
O
BnO
BnO
OMe
27
1H NMR (500 MHz, CDCl3)
51.39
0.24 1.05 0.28 1.30 0.94 6.23 0.42 5.74 0.90 4.51 0.30 0.23 0.23 0.18 1.00 0.32 2.57 1.31 0.26 0.33 0.45 2.30 0.60 0.53 3.81 4.92 1.01
0.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

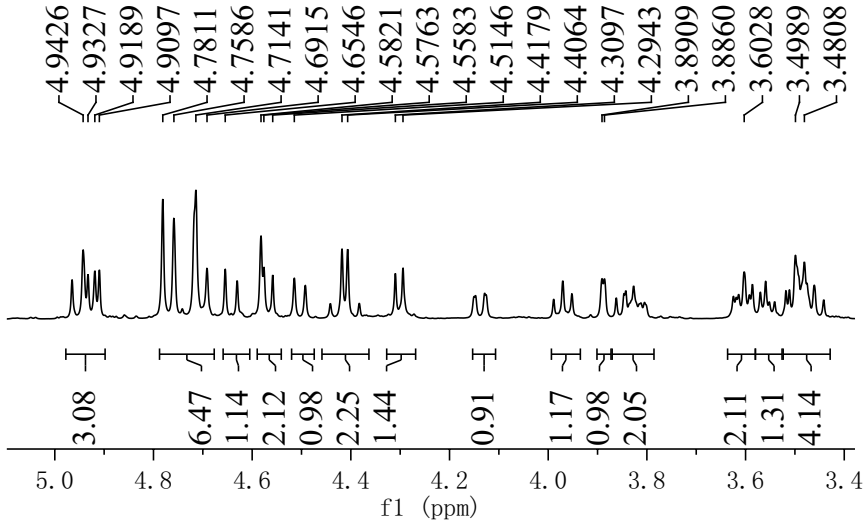

139.77
138.78
138.77
138.74
138.68
138.58
138.51
138.36
138.03
128.60
128.51
128.49
128.43
128.38
128.24
128.15
128.12
127.93
127.91
127.88
127.77
127.72
127.67
127.44
127.21
126.91
102.64
98.59
97.93
96.82
85.04
82.99
80.58
80.38
79.66
79.03
78.23
77.84
77.41
77.16
76.91
75.73
75.52
75.35
75.07
74.93
73.77
73.61
73.52
73.50
73.38
73.32
70.14
69.19
68.39
68.05
55.44
55.30
OBn
O
BnO
BnO
BnO
O
OBn
O
BnO
BnO
OMe
27
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

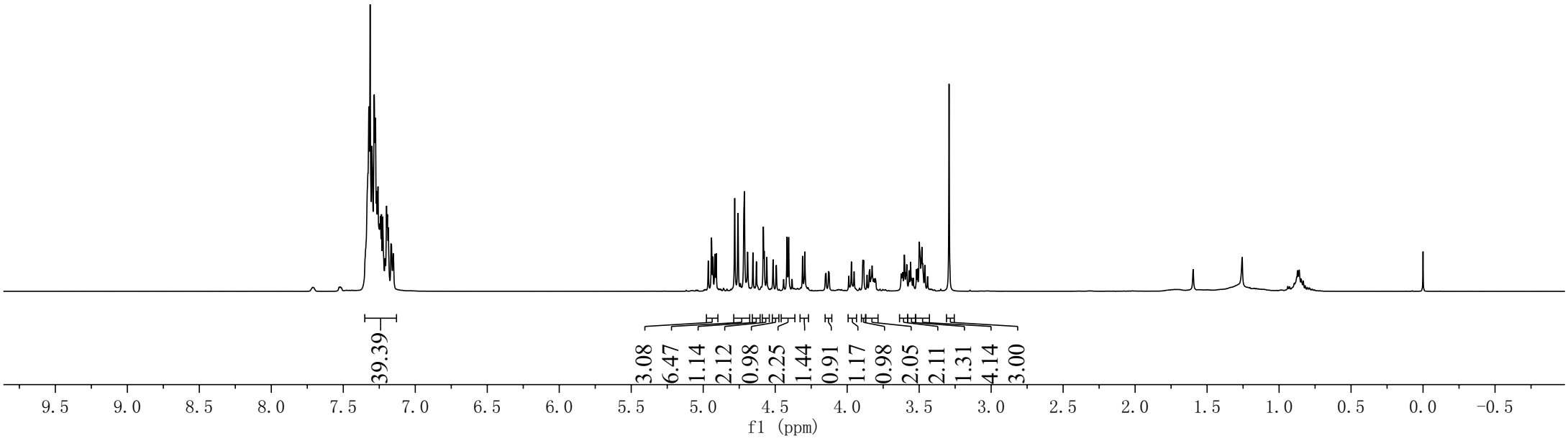

28
$^1$H NMR (500 MHz, CDCl$_3$)
f1 (ppm)

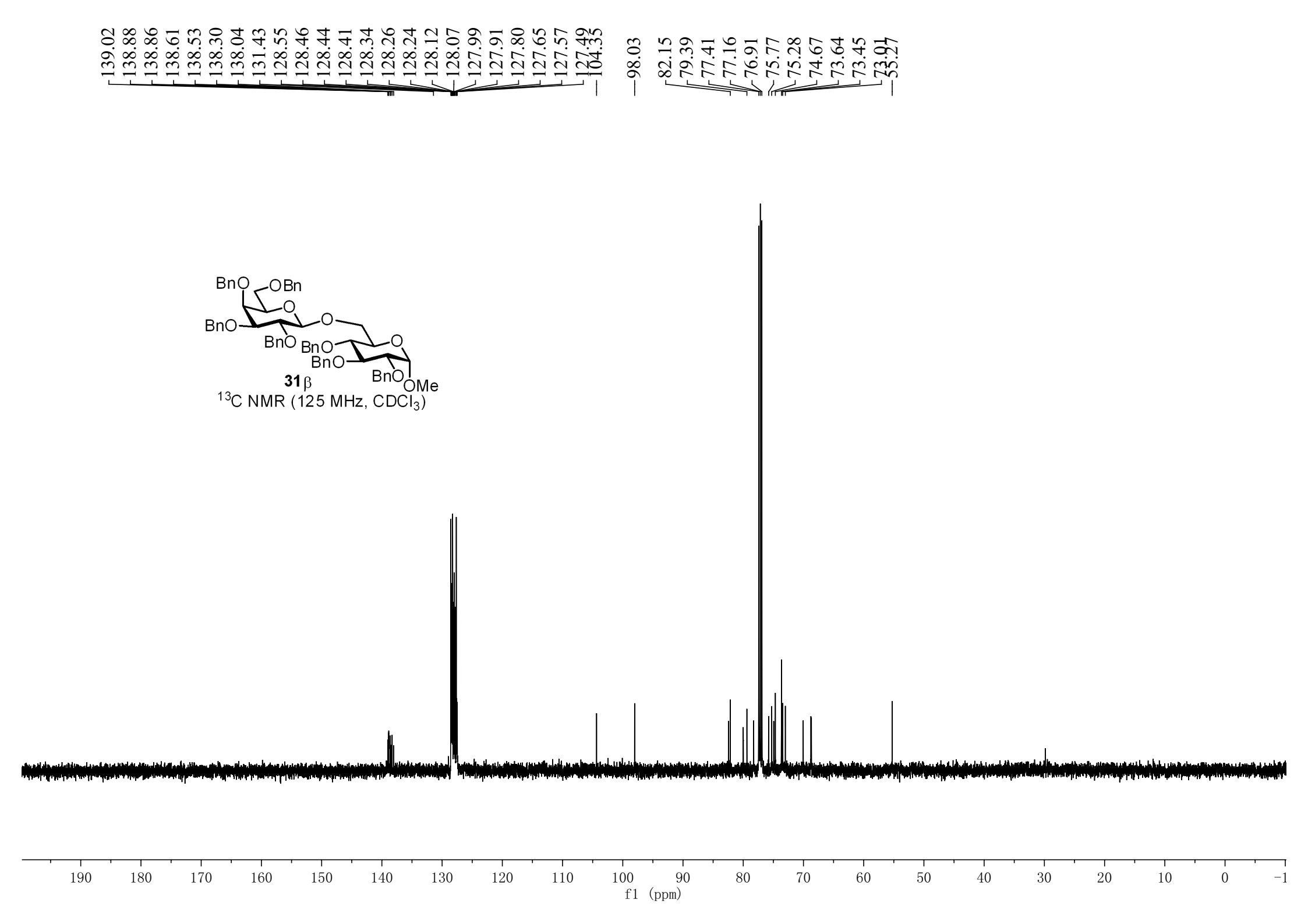

139.11
138.84
138.68
138.57
138.51
138.21
138.15
128.45
128.38
128.35
128.32
128.27
128.23
128.16
128.14
128.08
127.96
127.90
127.85
127.83
127.74
127.67
127.64
127.52
127.46
127.44
127.38
127.33
127.06
103.96
102.81
98.06
83.16
82.61
82.03
81.57
80.04
79.88
78.04
77.29
77.04
76.78
76.70
75.65
75.40
75.35
75.26
75.03
74.84
74.73
73.41
73.35
73.06
72.64
69.98
68.58
68.14
55.19
BnO
OBn
OBn
BnO
BnO
BnO
BnO
BnO
BnO
BnO
BnO
OMe
28
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

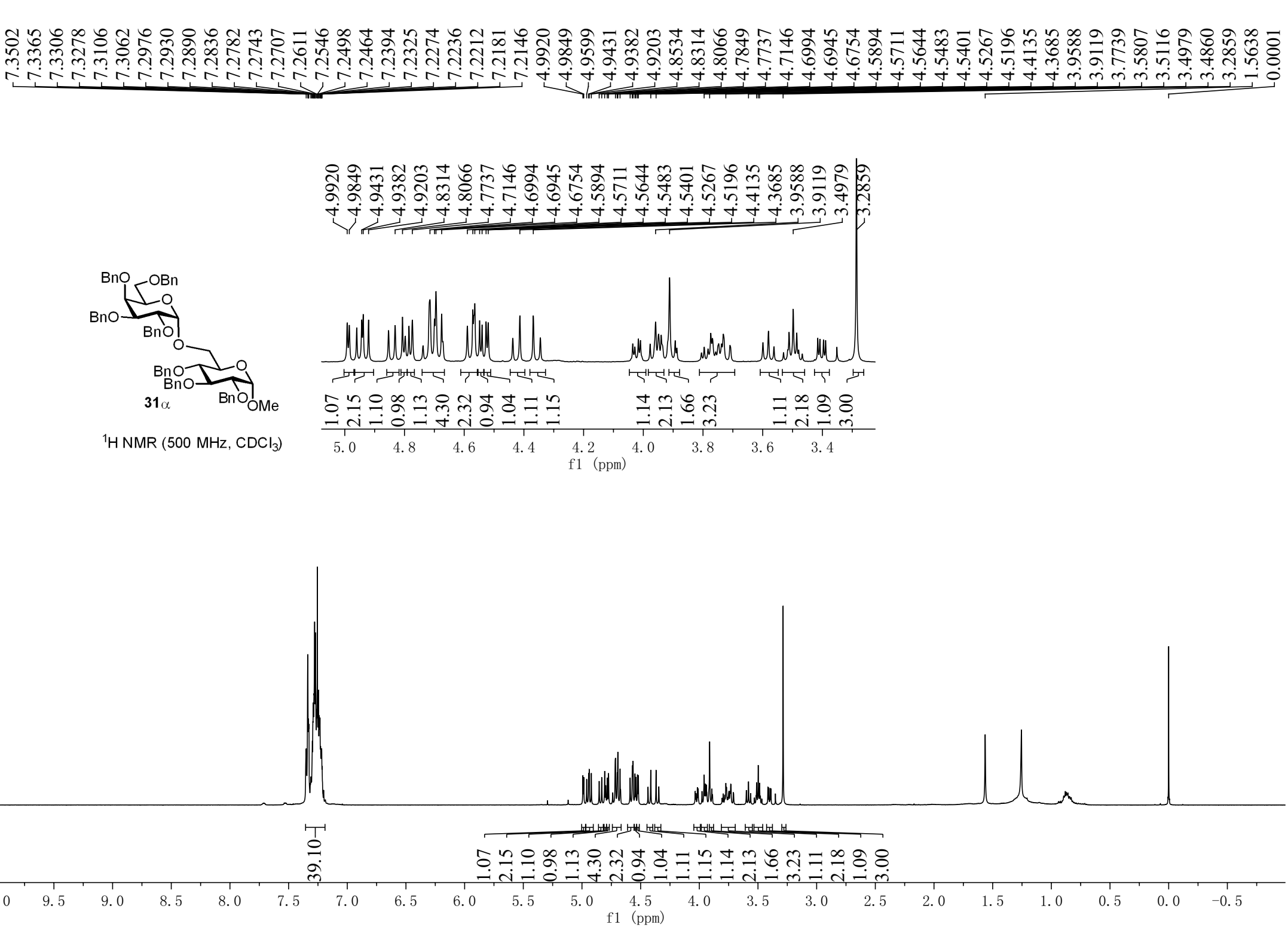



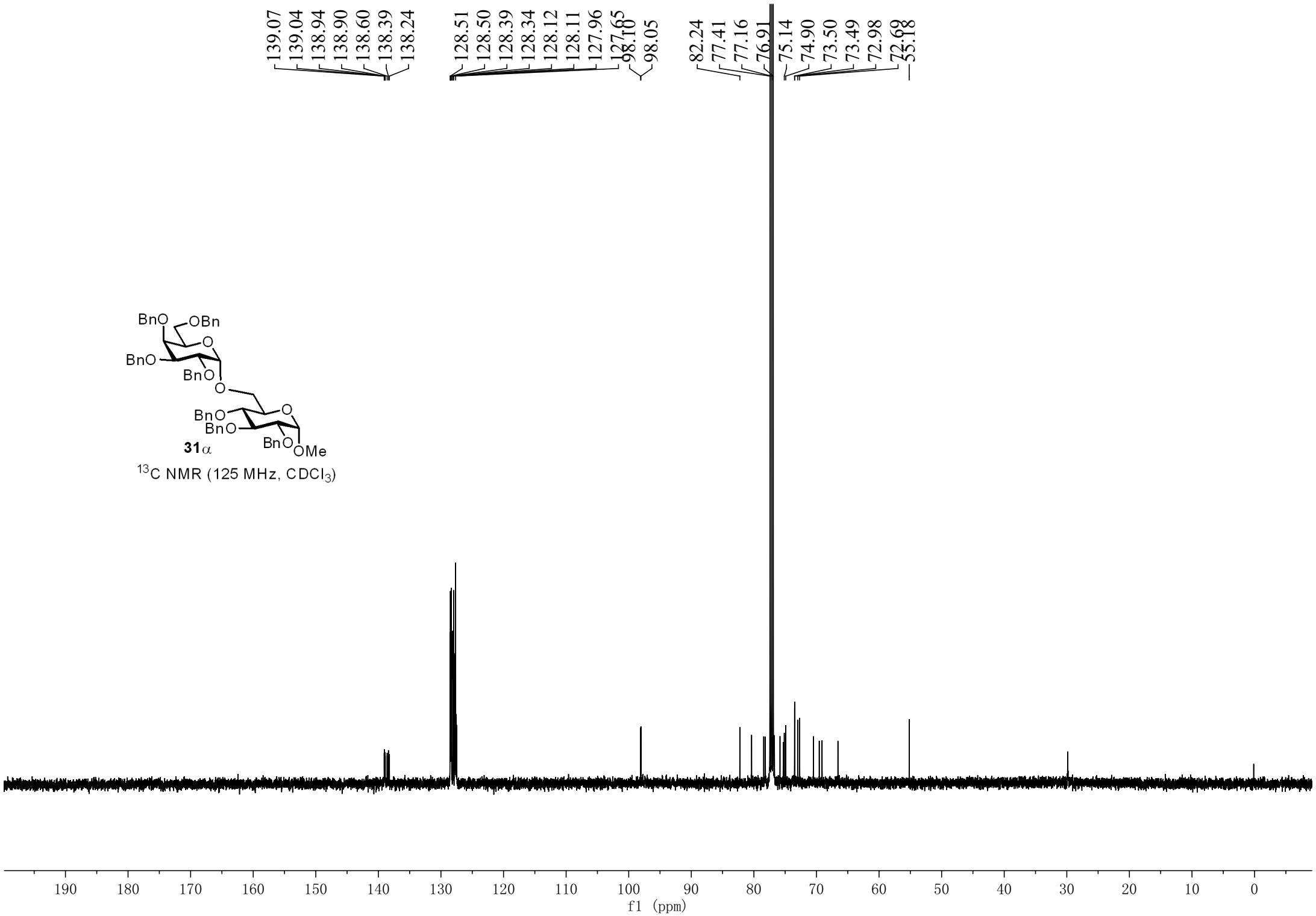

$^1$H NMR (500 MHz, $CDCl_3$)

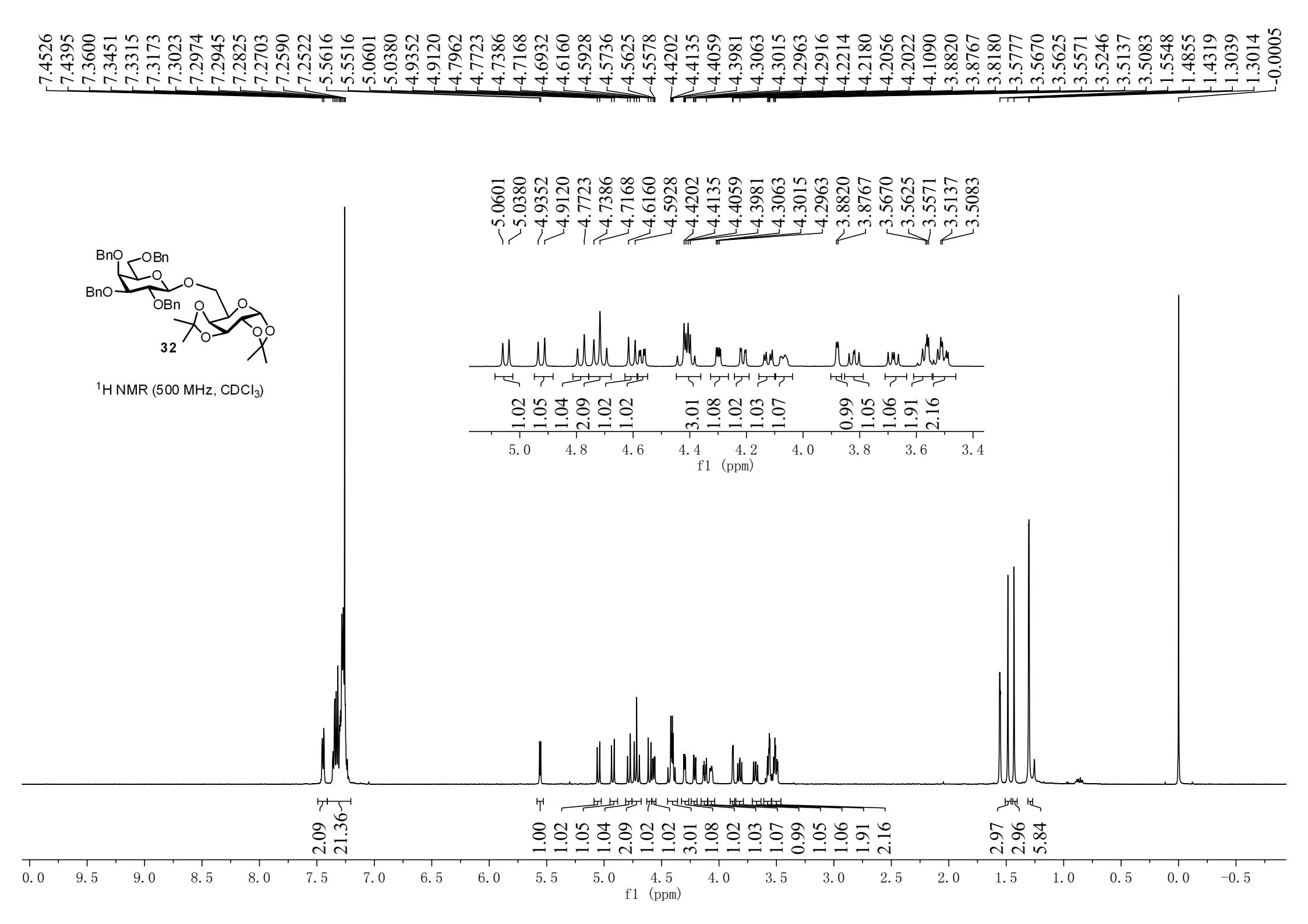


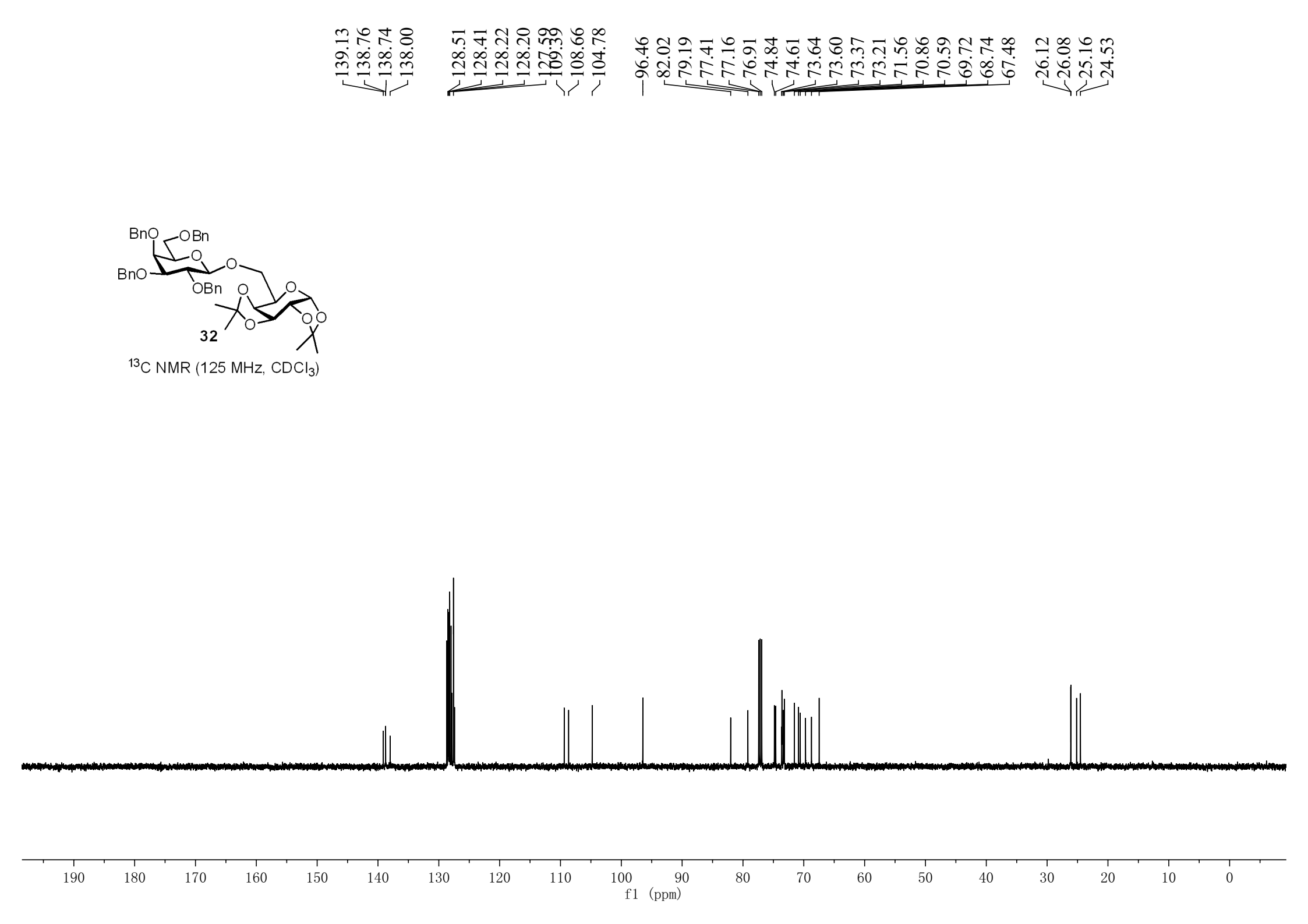



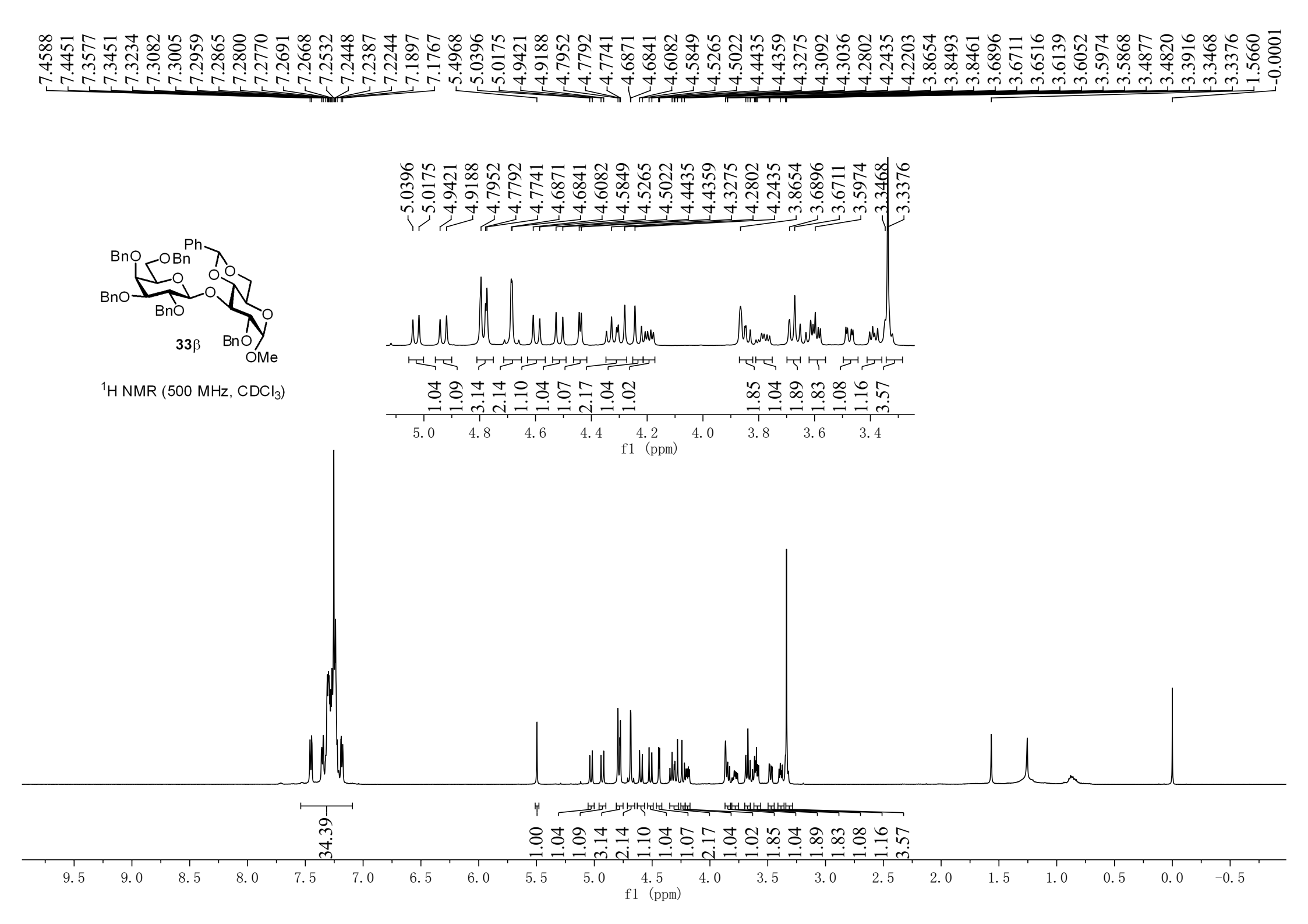

139.02
138.88
138.86
138.61
138.53
138.30
138.04
131.43
128.55
128.46
128.44
128.41
128.34
128.26
128.24
128.12
128.07
127.99
127.91
127.80
127.65
127.57
127.49
104.35
98.03
82.15
79.39
77.41
77.16
76.91
75.77
75.28
74.67
73.64
73.45
73.01
55.27
BnO
OBn
O
O
BnO
BnO
BnO
BnO
O
BnO
BnO
OMe
31β
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-1
f1 (ppm)


7.3502 7.3365 7.3306 7.3278 7.3106 7.3062 7.2976 7.2930 7.2890 7.2836 7.2782 7.2743 7.2707 7.2611 7.2546 7.2498 7.2464 7.2394 7.2325 7.2274 7.2236 7.2212 7.2181 7.2146
4.9920 4.9849 4.9599 4.9431 4.9382 4.9203 4.8534 4.8314 4.8066 4.7849 4.7737 4.7146 4.6994 4.6945 4.6754 4.5894 4.5711 4.5644 4.5483 4.5401 4.5267 4.5196 4.4135 4.3685 3.9588 3.9119 3.7739 3.5807 3.5116 3.4979 3.4860 3.2859 1.5638 0.0001
BnO OBn BnO BnO BnO BnO BnO BnO OMe
31α
1H NMR (500 MHz, CDCl3)
4.9920 4.9849 4.9431 4.9382 4.9203 4.8314 4.8066 4.7737 4.7146 4.6994 4.6945 4.6754 4.5894 4.5711 4.5644 4.5483 4.5401 4.5267 4.5196 4.4135 4.3685 3.9588 3.9119 3.4979 3.2859
1.07 2.15 1.10 0.98 1.13 4.30 2.32 0.94 1.04 1.11 1.15 1.14 2.13 1.66 3.23 1.11 2.18 1.09 3.00
5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4
f1 (ppm)
39.10
1.07 2.15 1.10 0.98 1.13 4.30 2.32 0.94 1.04 1.11 1.15 1.14 2.13 1.66 3.23 1.11 2.18 1.09 3.00
0.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

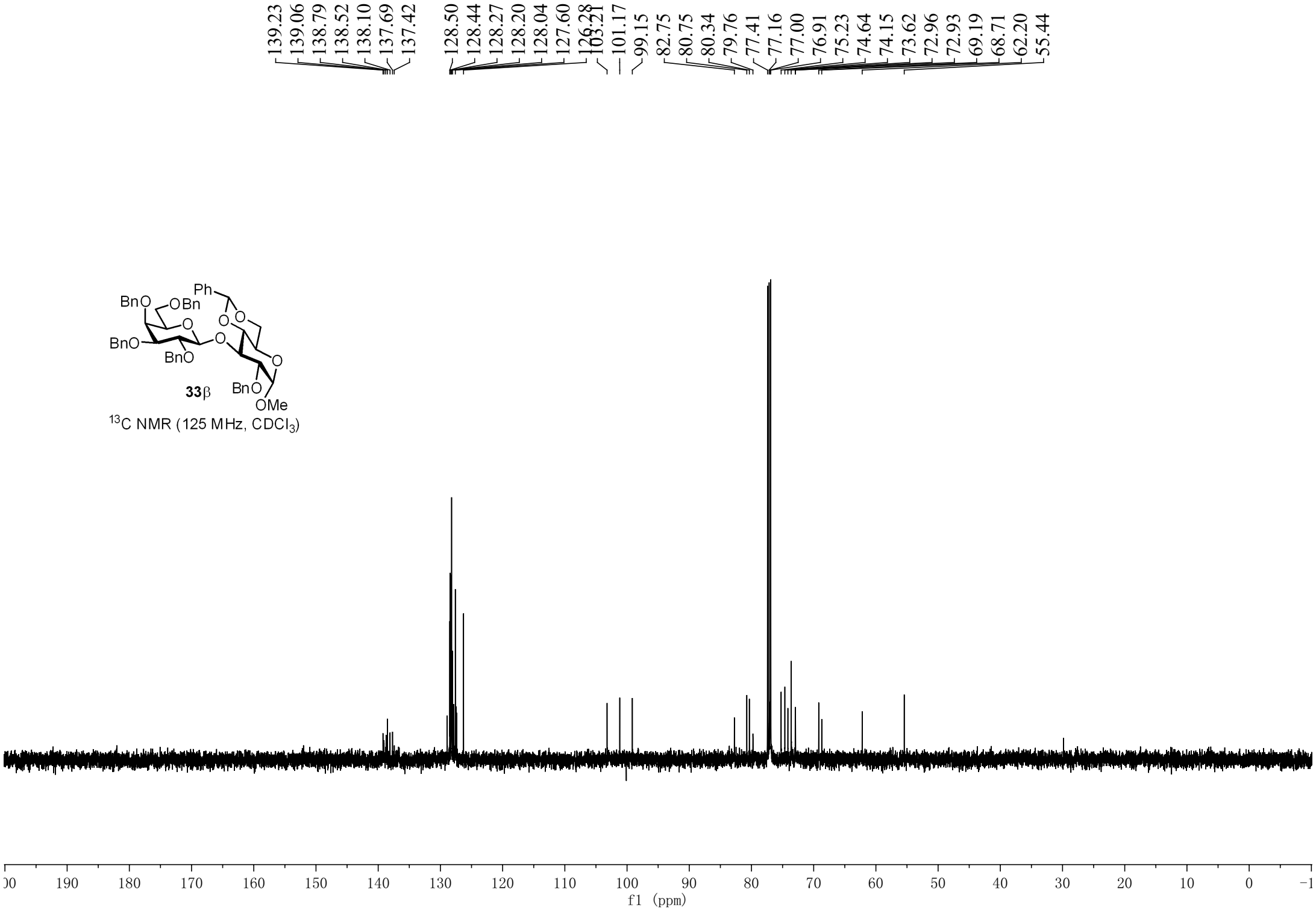

139.07
139.04
138.94
138.90
138.60
138.39
138.24
128.51
128.50
128.39
128.34
128.12
128.11
127.96
127.65
98.10
98.05
82.24
77.41
77.16
76.91
75.14
74.90
73.50
73.49
72.98
72.69
55.18
BnO
OBn
O
BnO
BnO
O
BnO
BnO
O
BnO
OMe
31α
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

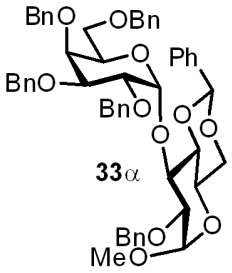

BnO
OBn
BnO
OBn
O
O
O
O
O
O
O
32
$^1$H NMR (500 MHz, $CDCl_3$)
f1 (ppm)


139.13
138.76
138.74
138.00
128.51
128.41
128.22
128.20
127.59
109.39
108.66
104.78
96.46
82.02
79.19
77.41
77.16
76.91
74.84
74.61
73.64
73.60
73.37
73.21
71.56
70.86
70.59
69.72
68.74
67.48
26.12
26.08
25.16
24.53
BnO
OBn
BnO
OBn
O
O
O
O
O
O
O
O
32
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

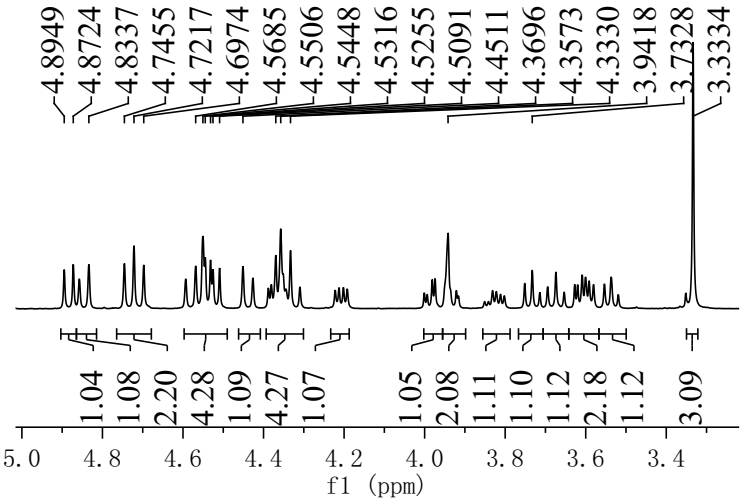


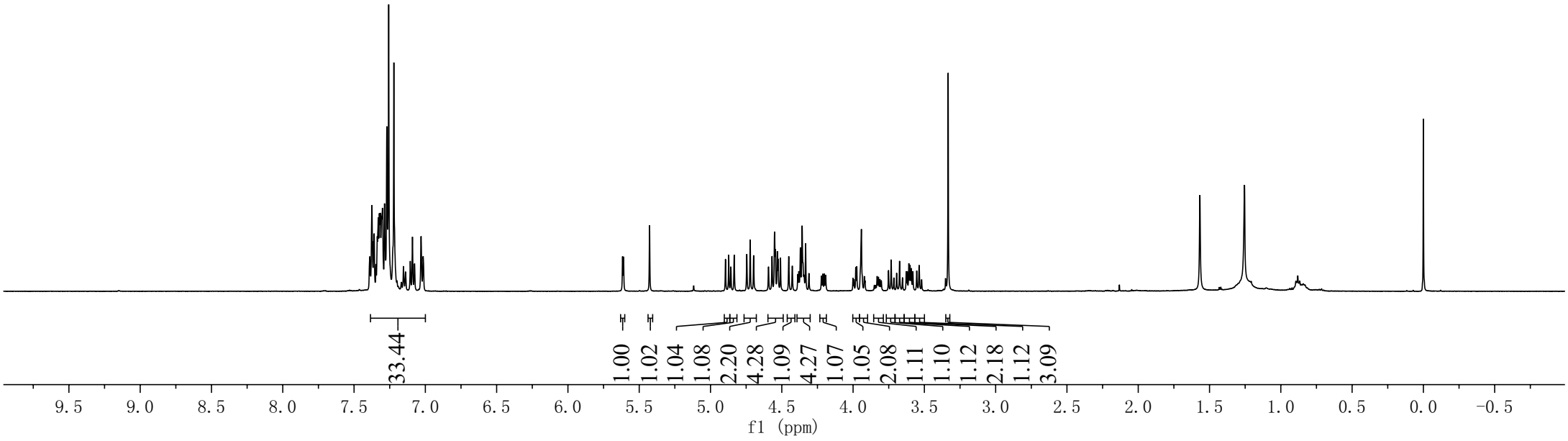

$^1$H NMR (500 MHz, $CDCl_3$)

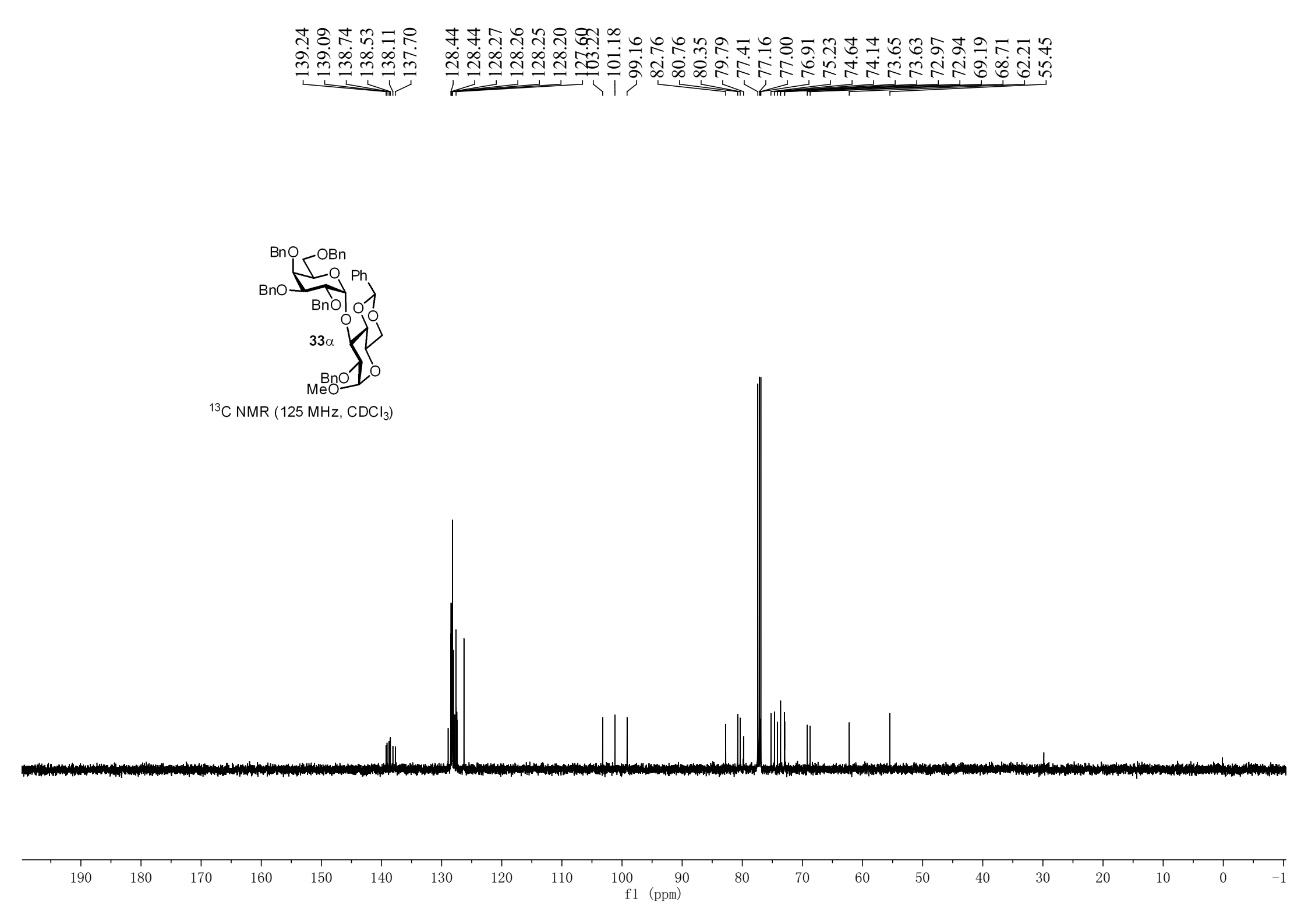

139.23
139.06
138.79
138.52
138.10
137.69
137.42
128.50
128.44
128.27
128.20
128.04
127.60
126.28
103.21
101.17
99.15
82.75
80.75
80.34
79.76
77.41
77.16
77.00
76.91
75.23
74.64
74.15
73.62
72.96
72.93
69.19
68.71
62.20
55.44
Ph
BnO
OBn
BnO
BnO
O
O
O
O
O
O
BnO
OMe
33β
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

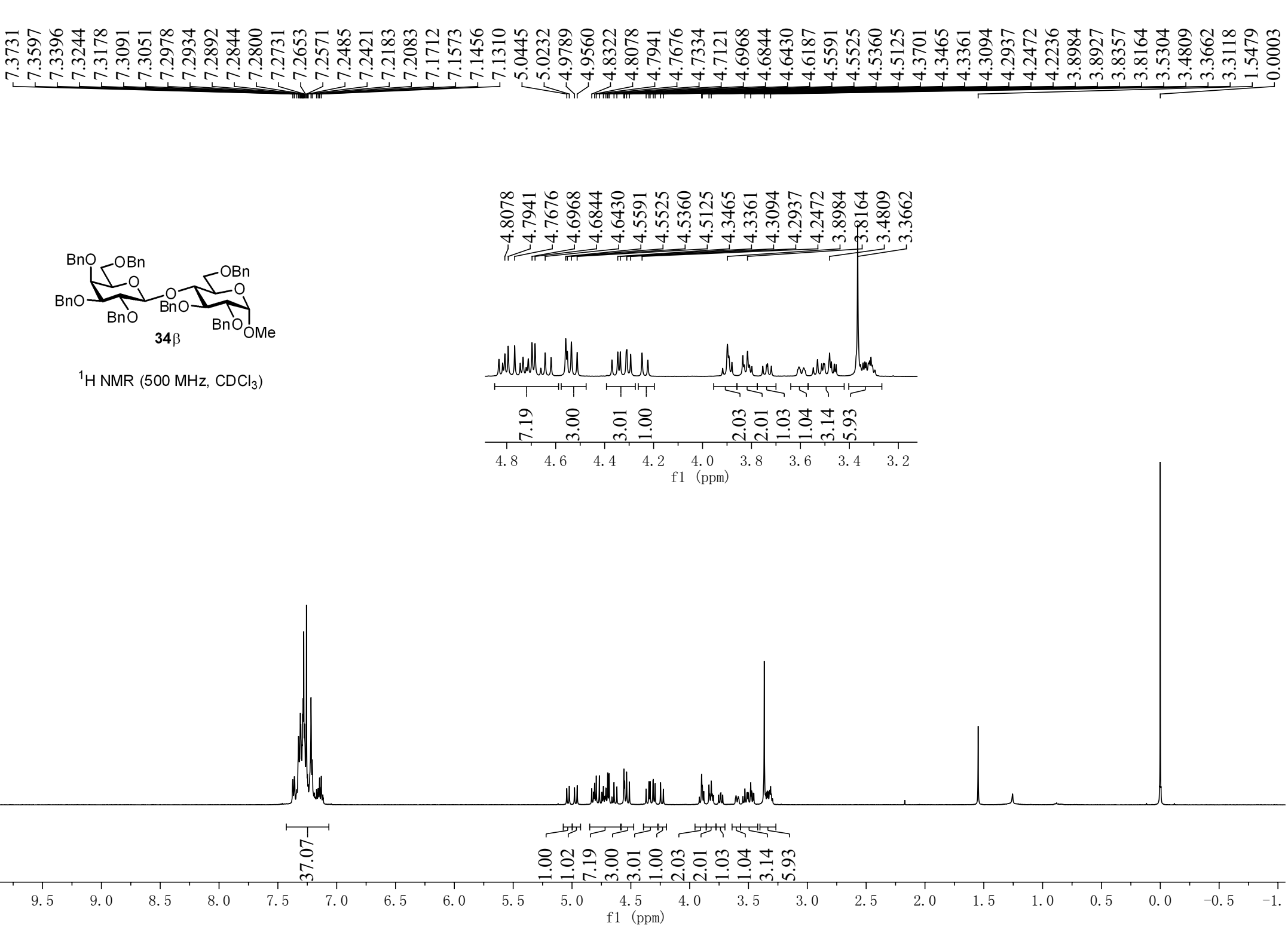



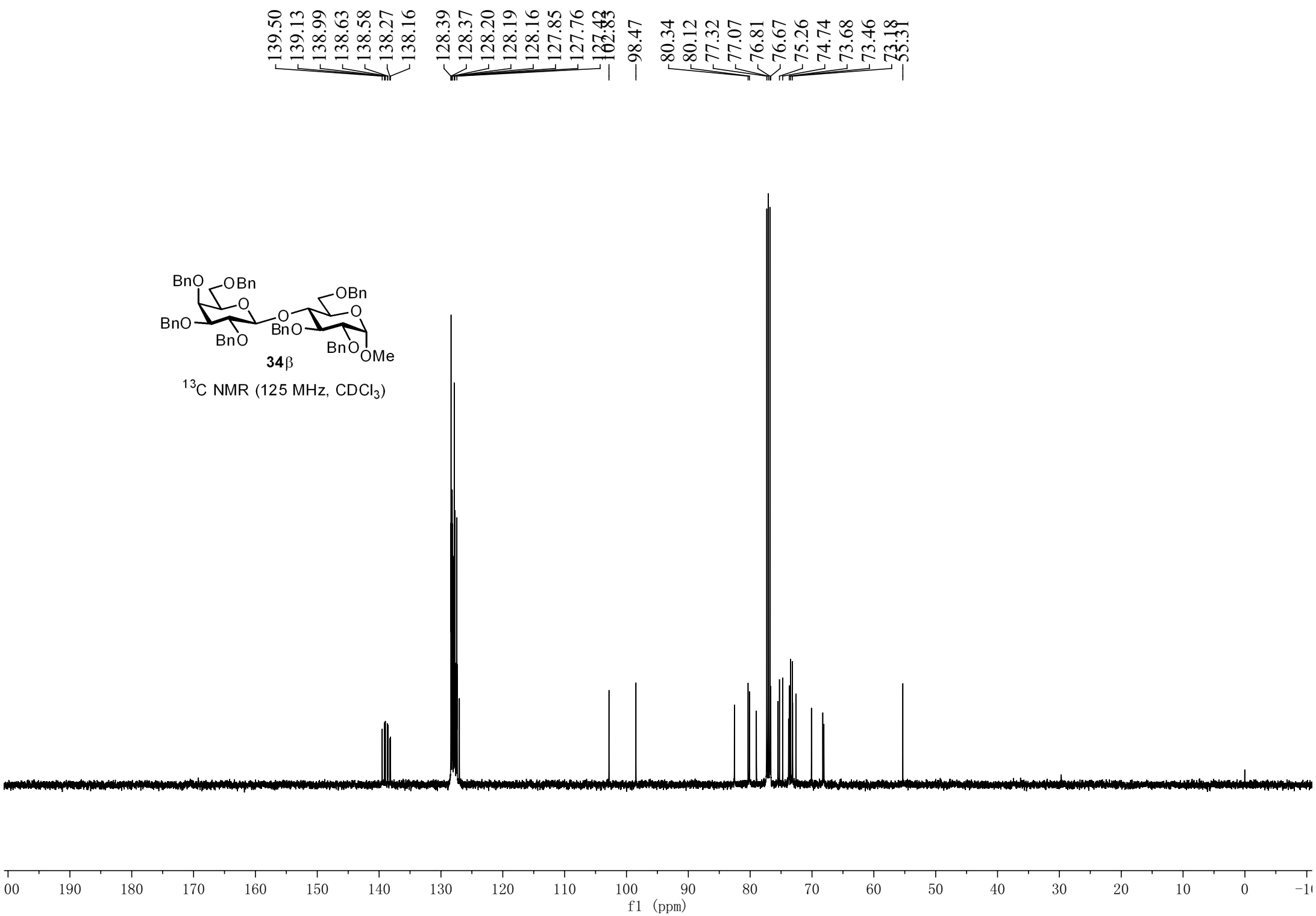

$^1$H NMR (500 MHz, $CDCl_3$)

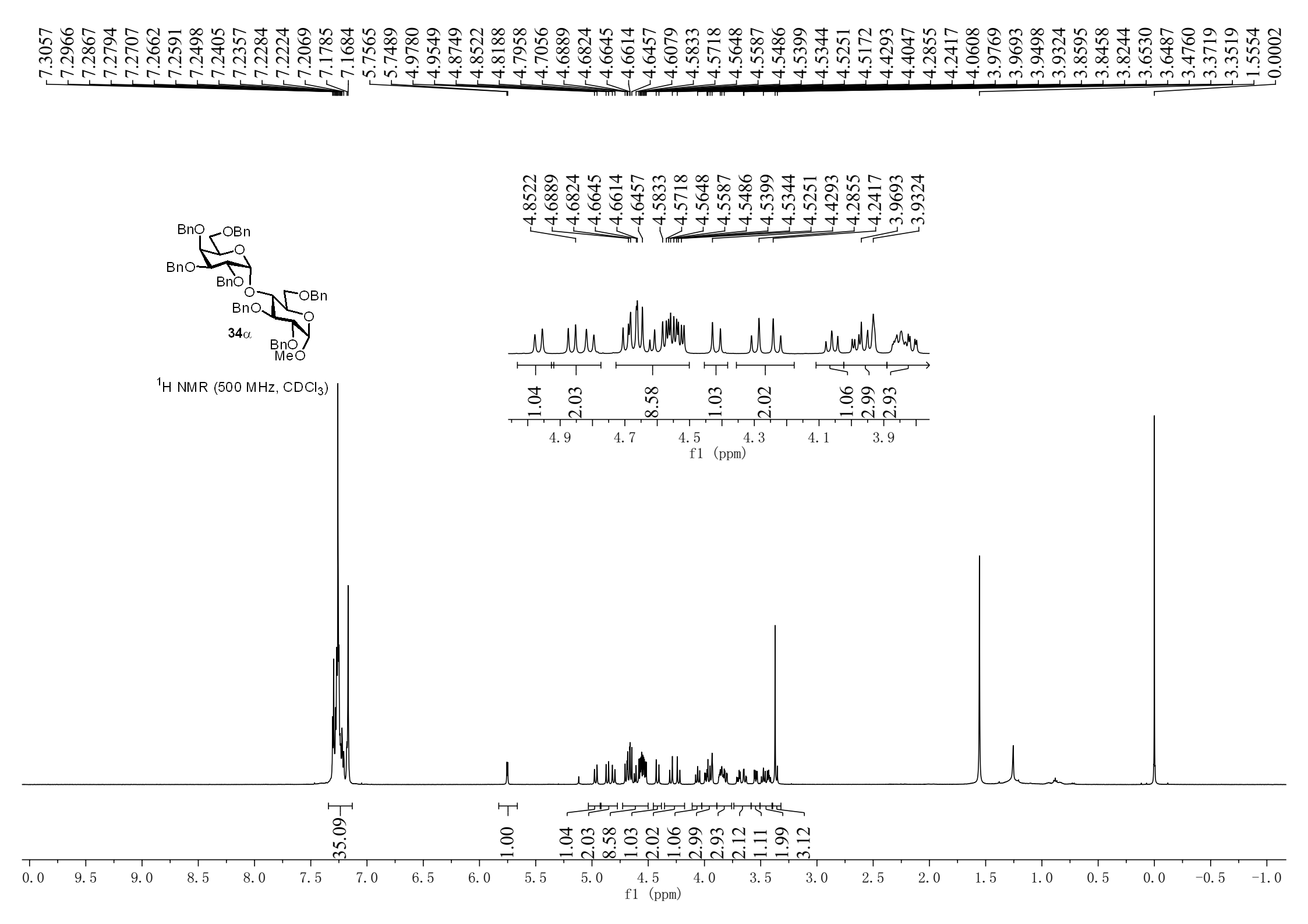


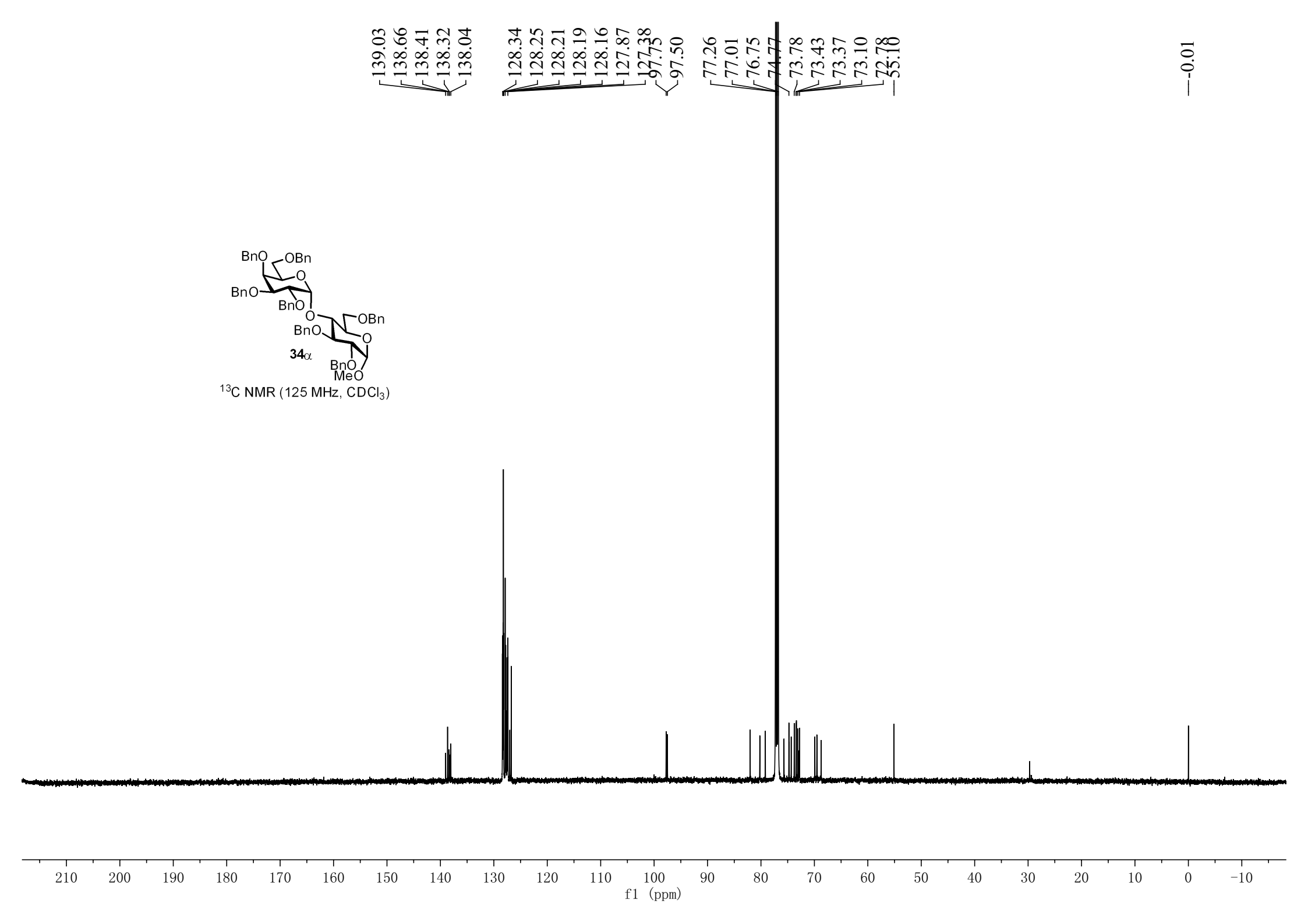



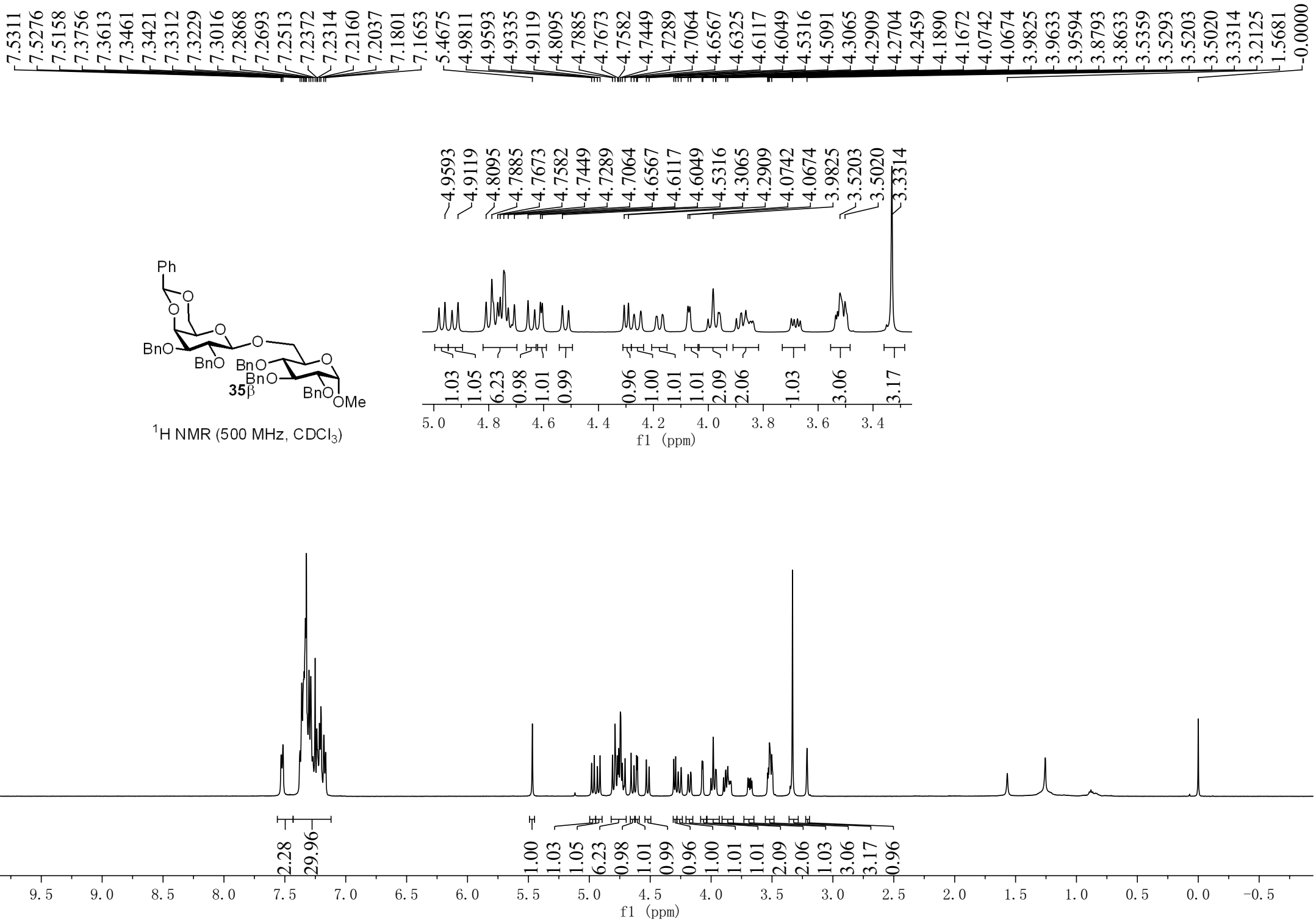

139.24
139.09
138.74
138.53
138.11
137.70
128.44
128.44
128.27
128.26
128.25
128.20
127.60
103.22
101.18
99.16
82.76
80.76
80.35
79.79
77.41
77.16
77.00
76.91
75.23
74.64
74.14
73.65
73.63
72.97
72.94
69.19
68.71
62.21
55.45
BnO
OBn
O
Ph
BnO
BnO
O
O
O
33α
BnO
MeO
O
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−1
f1 (ppm)

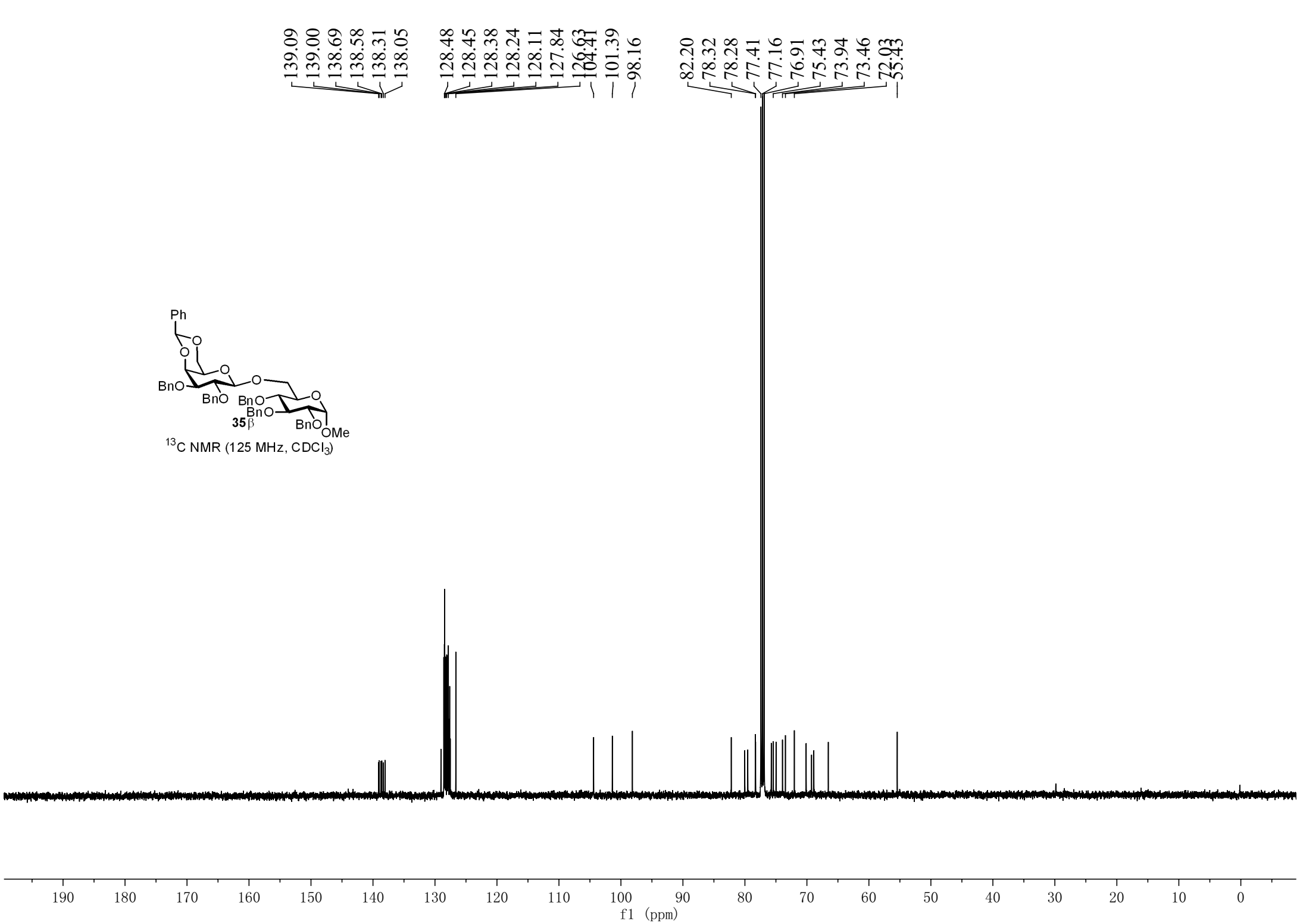

7.3731 7.3597 7.3396 7.3244 7.3178 7.3091 7.3051 7.2978 7.2934 7.2892 7.2844 7.2800 7.2731 7.2653 7.2571 7.2485 7.2421 7.2183 7.2083 7.1712 7.1573 7.1456 7.1310
5.0445 5.0232 4.9789 4.9560 4.8322 4.8078 4.7941 4.7676 4.7334 4.7121 4.6968 4.6844 4.6430 4.6187 4.5591 4.5525 4.5360 4.5125 4.3701 4.3465 4.3361 4.3094 4.2937 4.2472 4.2236 3.8984 3.8927 3.8357 3.8164 3.5304 3.4809 3.3662 3.3118 1.5479 0.0003
BnO OBn O BnO O OBn O BnO BnO BnO OMe
34β
1H NMR (500 MHz, CDCl3)
4.8078 4.7941 4.7676 4.6968 4.6844 4.6430 4.5591 4.5525 4.5360 4.5125 4.3465 4.3361 4.3094 4.2937 4.2472 3.8984 3.8164 3.4809 3.3662
7.19 3.00 3.01 1.00 2.03 2.01 1.03 1.04 3.14 5.93
4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2
f1 (ppm)
37.07
1.00 1.02 7.19 3.00 3.01 1.00 2.03 2.01 1.03 1.04 3.14 5.93
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5 -1.
f1 (ppm)

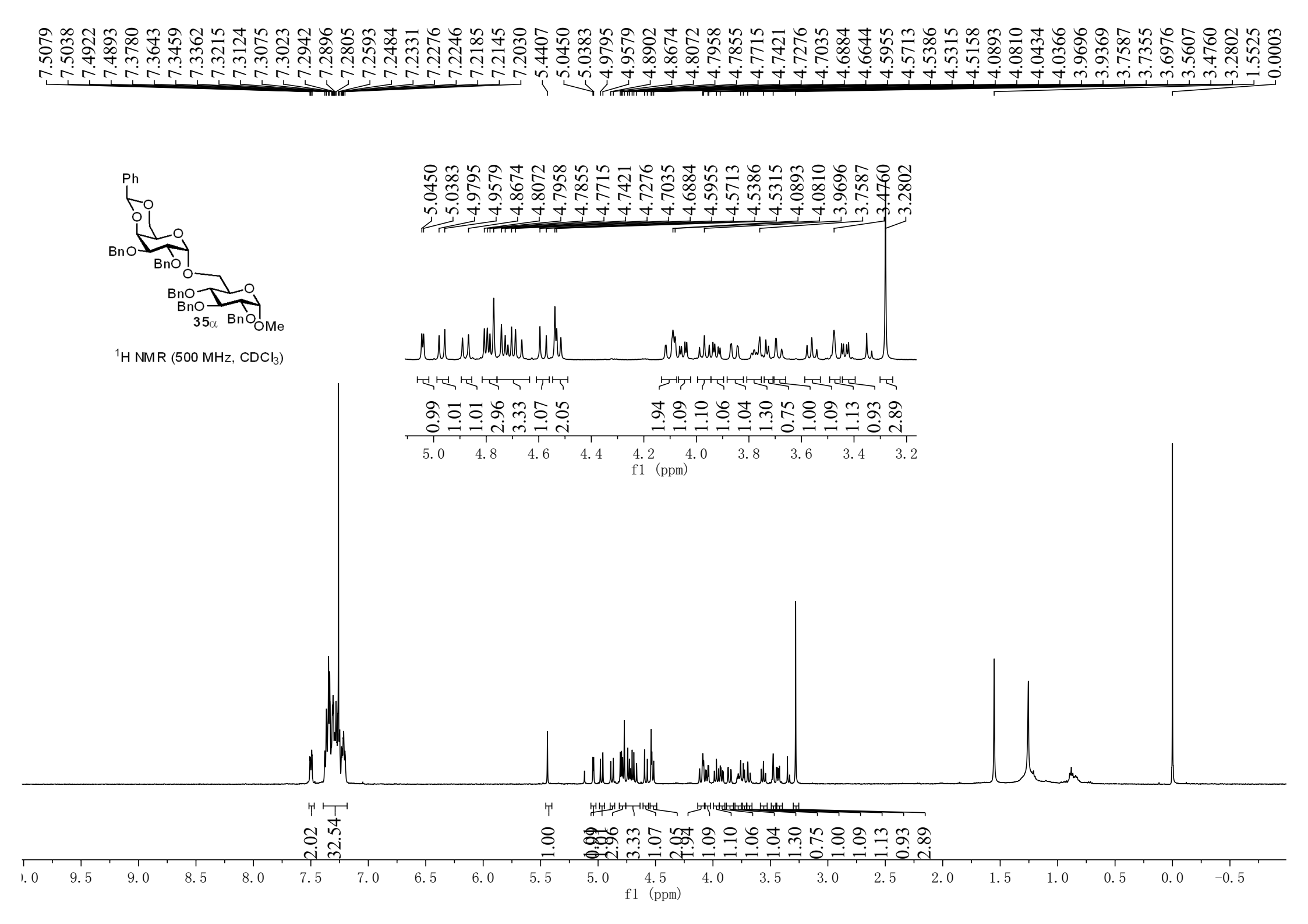

139.50
139.13
138.99
138.63
138.58
138.27
138.16
128.39
128.37
128.20
128.19
128.16
127.85
127.76
127.42
102.83
98.47
80.34
80.12
77.32
77.07
76.81
76.67
75.26
74.74
73.68
73.46
73.18
55.31
BnO
OBn
O
BnO
BnO
O
OBn
O
BnO
BnO
OMe
34β
13C NMR (125 MHz, CDCl3)
f1 (ppm)

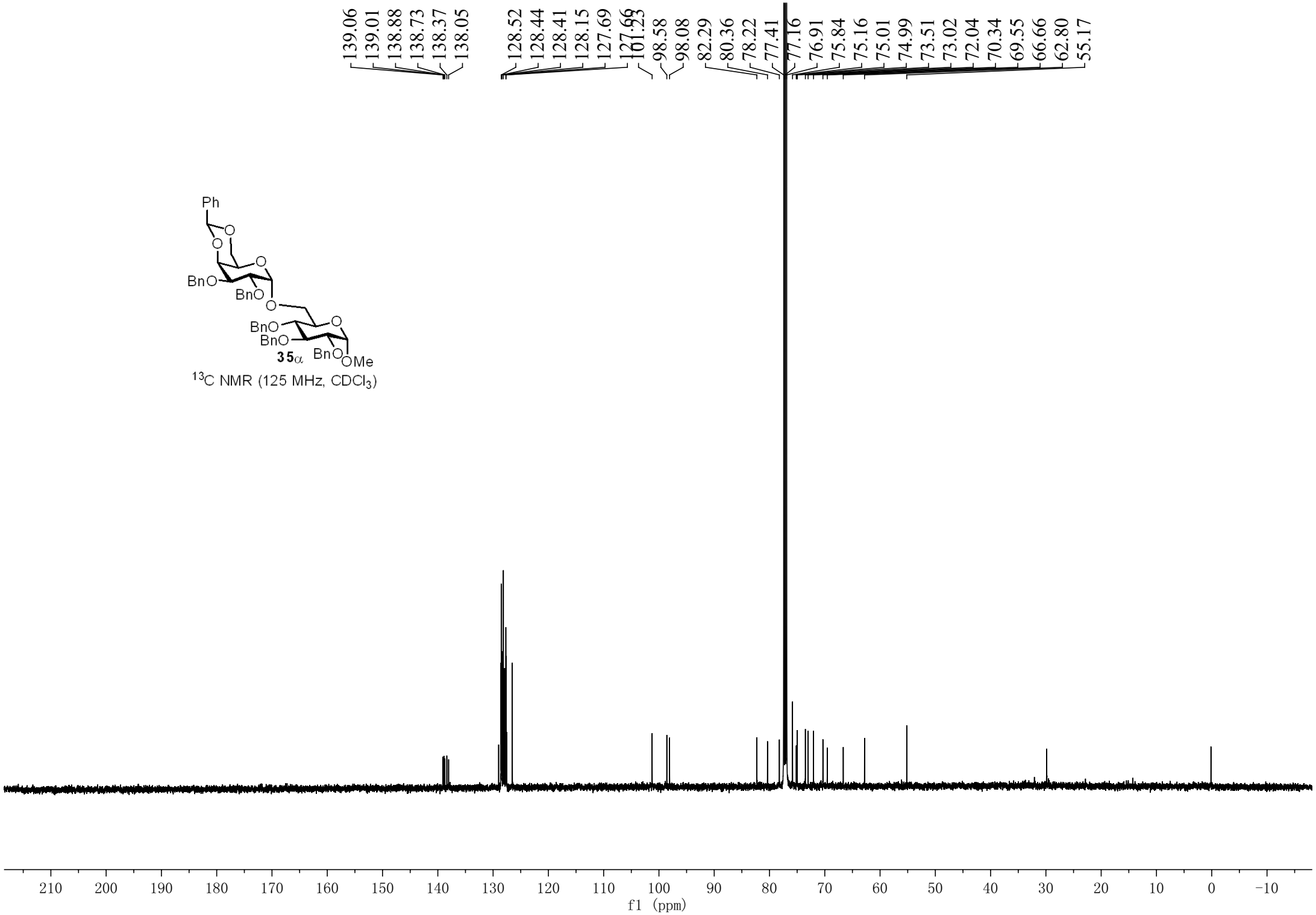

7.3057
7.2966
7.2867
7.2794
7.2707
7.2662
7.2591
7.2498
7.2405
7.2357
7.2284
7.2224
7.2069
7.1785
7.1684
5.7565
5.7489
4.9780
4.9549
4.8749
4.8522
4.8188
4.7958
4.7056
4.6889
4.6824
4.6645
4.6614
4.6457
4.6079
4.5833
4.5718
4.5648
4.5587
4.5486
4.5399
4.5344
4.5251
4.5172
4.4293
4.4047
4.2855
4.2417
4.0608
3.9769
3.9693
3.9498
3.9324
3.8595
3.8458
3.8244
3.6530
3.6487
3.4760
3.3719
3.3519
1.5554
0.0002
BnO
OBn
O
BnO
BnO
O
OBn
BnO
O
34α
BnO
MeO
1H NMR (500 MHz, CDCl3)
4.8522
4.6889
4.6824
4.6645
4.6614
4.6457
4.5833
4.5718
4.5648
4.5587
4.5486
4.5399
4.5344
4.5251
4.4293
4.2855
4.2417
3.9693
3.9324
1.04
2.03
8.58
1.03
2.02
1.06
2.99
2.93
4.9
4.7
4.5
4.3
4.1
3.9
f1 (ppm)
35.09
1.00
1.04
2.03
8.58
1.03
2.02
1.06
2.99
2.93
2.12
1.11
1.99
3.12
0.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
f1 (ppm)

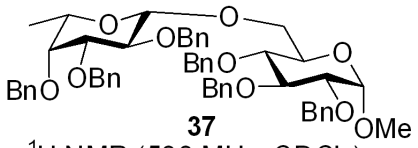

139.03
138.66
138.41
138.32
138.04
128.34
128.25
128.21
128.19
128.16
127.87
127.38
97.75
97.50
77.26
77.01
76.75
74.77
73.78
73.43
73.37
73.10
72.78
55.10
-0.01
BnO
OBn
O
BnO
BnO
O
OBn
BnO
O
34α
BnO
MeO
13C NMR (125 MHz, CDCl3)
f1 (ppm)


7.5311
7.5276
7.5158
7.3756
7.3613
7.3461
7.3421
7.3312
7.3229
7.3016
7.2868
7.2693
7.2513
7.2372
7.2314
7.2160
7.2037
7.1801
7.1653
5.4675
4.9811
4.9593
4.9335
4.9119
4.8095
4.7885
4.7673
4.7582
4.7449
4.7289
4.7064
4.6567
4.6325
4.6117
4.6049
4.5316
4.5091
4.3065
4.2909
4.2704
4.2459
4.1890
4.1672
4.0742
4.0674
3.9825
3.9633
3.9594
3.8793
3.8633
3.5359
3.5293
3.5203
3.5020
3.3314
3.2125
1.5681
-0.0000
Ph
BnO
BnO
BnO
BnO
BnO
OMe
35β
1H NMR (500 MHz, CDCl3)
4.9593
4.9119
4.8095
4.7885
4.7673
4.7582
4.7449
4.7289
4.7064
4.6567
4.6117
4.6049
4.5316
4.3065
4.2909
4.0742
4.0674
3.9825
3.5203
3.5020
3.3314
1.03
1.05
6.23
0.98
1.01
0.99
0.96
1.00
1.01
1.01
2.09
2.06
1.03
3.06
3.17
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
f1 (ppm)
2.28
29.96
1.00
1.03
1.05
6.23
0.98
1.01
0.99
0.96
1.00
1.01
1.01
2.09
2.06
1.03
3.06
3.17
0.96
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


139.09
139.00
138.69
138.58
138.31
138.05
128.48
128.45
128.38
128.24
128.11
127.84
126.63
104.41
101.39
98.16
82.20
78.32
78.28
77.41
77.16
76.91
75.43
73.94
73.46
72.03
55.43
Ph
BnO
BnO
BnO
BnO
35β
BnO
OMe
13C NMR (125 MHz, CDCl3)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


7.5079
7.5038
7.4922
7.4893
7.3780
7.3643
7.3459
7.3362
7.3215
7.3124
7.3075
7.3023
7.2942
7.2896
7.2805
7.2593
7.2484
7.2331
7.2276
7.2246
7.2185
7.2145
7.2030
5.4407
5.0450
5.0383
4.9795
4.9579
4.8902
4.8674
4.8072
4.7958
4.7855
4.7715
4.7421
4.7276
4.7035
4.6884
4.6644
4.5955
4.5713
4.5386
4.5315
4.5158
4.0893
4.0810
4.0434
4.0366
3.9696
3.9369
3.7587
3.7355
3.6976
3.5607
3.4760
3.2802
1.5525
0.0003
Ph
BnO
BnO
BnO
BnO
BnO
35α
OMe
1H NMR (500 MHz, CDCl3)
0.99
1.01
1.01
2.96
3.33
1.07
2.05
1.94
1.09
1.10
1.06
1.04
1.30
0.75
1.00
1.09
1.13
0.93
2.89
f1 (ppm)
2.02
32.54
1.00
f1 (ppm)


139.06
139.01
138.88
138.73
138.37
138.05
128.52
128.44
128.41
128.15
127.69
127.66
101.23
98.58
98.08
82.29
80.36
78.22
77.41
77.16
76.91
75.84
75.16
75.01
74.99
73.51
73.02
72.04
70.34
69.55
66.66
62.80
55.17
Ph
BnO
BnO
BnO
BnO
BnO
OMe
35α
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

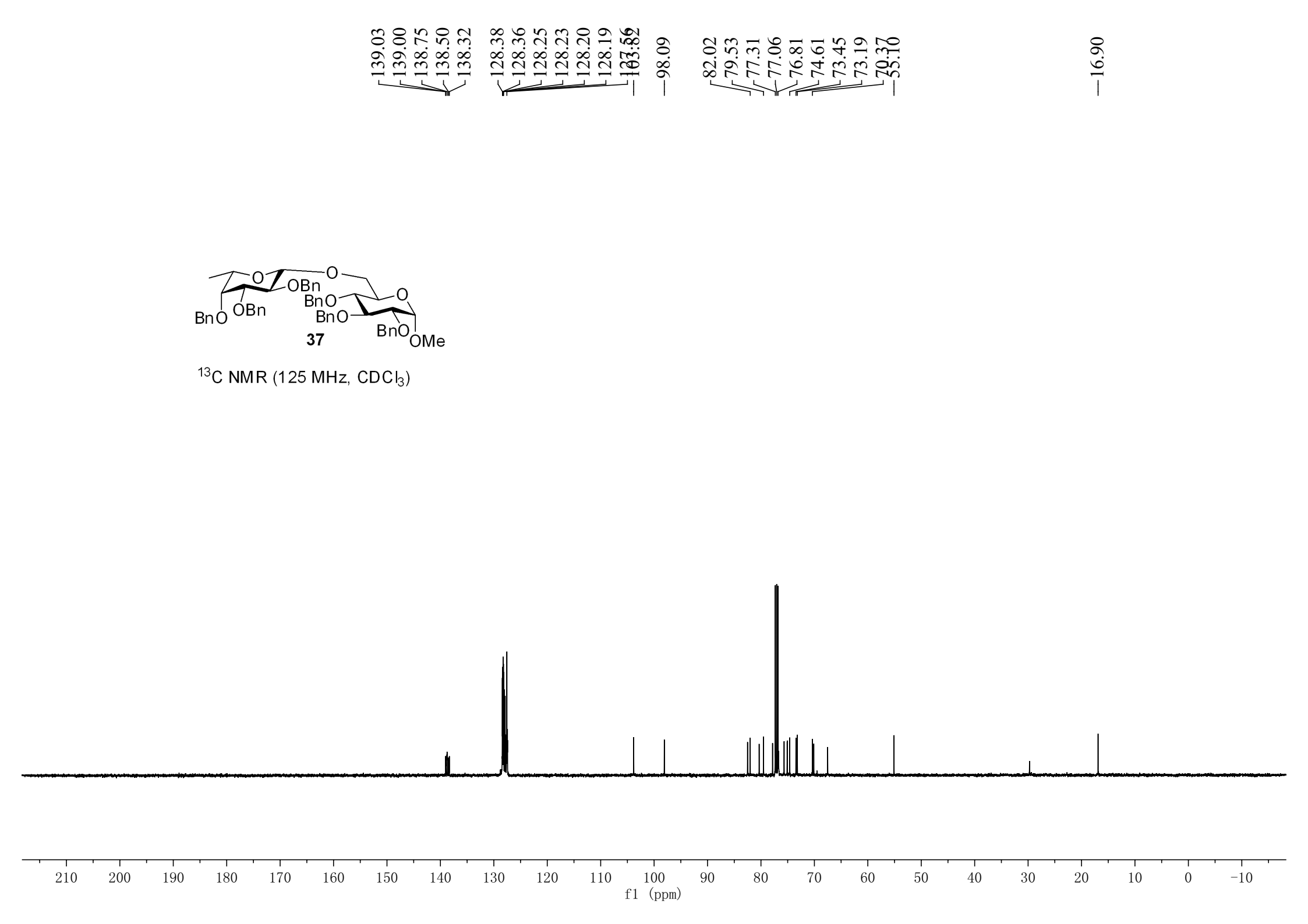



**37**

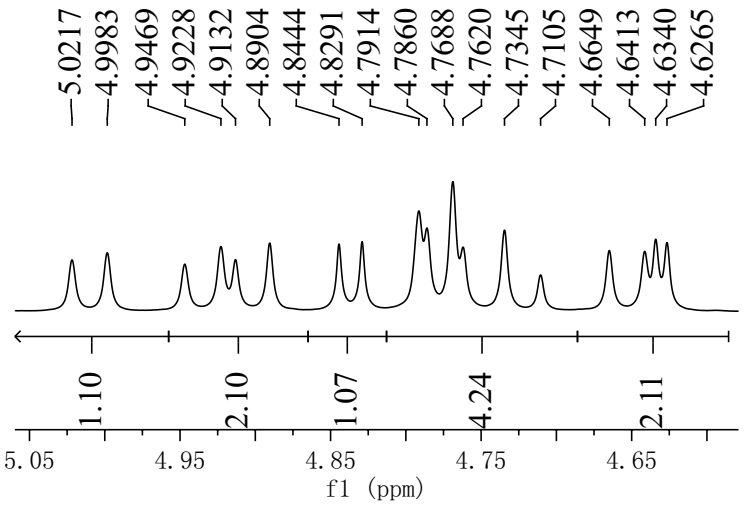
$^1$H NMR (500 MHz, $CDCl_3$)

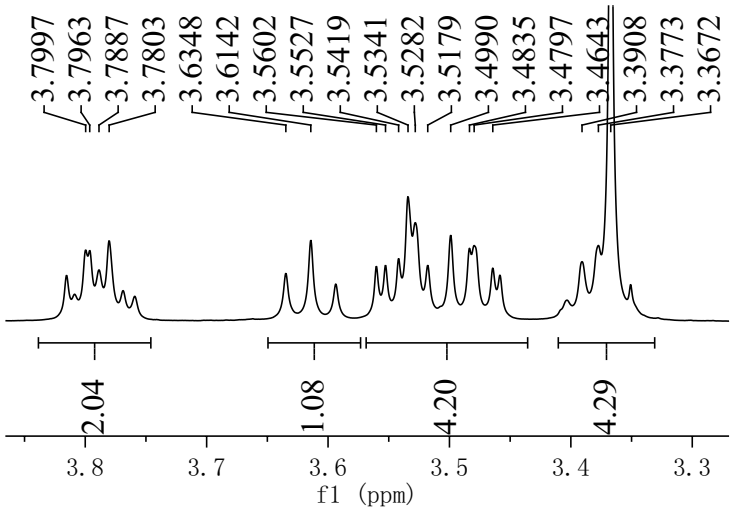
f1 (ppm)

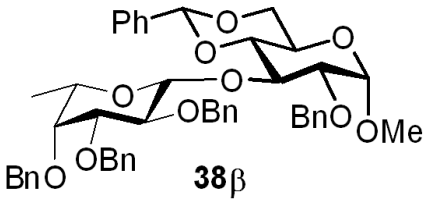
f1 (ppm)


139.03
139.00
138.75
138.50
138.32
128.38
128.36
128.25
128.23
128.20
128.19
98.09
82.02
79.53
77.31
77.06
76.81
74.61
73.45
73.19
55.10
16.90
BnO
OBn
OBn
BnO
BnO
BnO
OMe
37
13C NMR (125 MHz, CDCl3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)

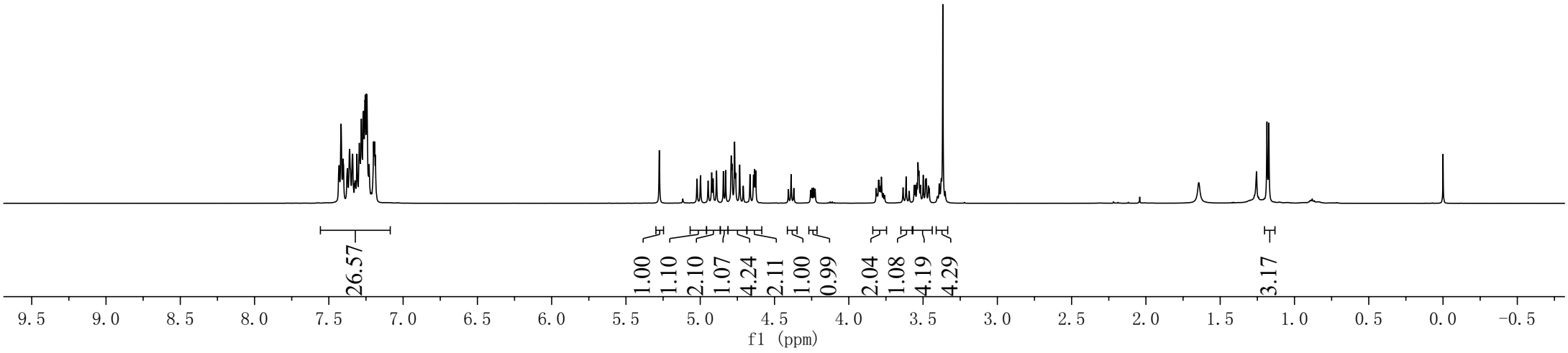

7.4312
7.4176
7.4043
7.3755
7.3599
7.3405
7.3271
7.3237
7.3106
7.2949
7.2906
7.2812
7.2690
7.2669
7.2576
7.2551
7.2466
7.2435
7.2342
7.2293
7.1990
7.1925
7.1864
5.2756
5.0217
4.9983
4.9469
4.9228
4.9132
4.8904
4.8444
4.8291
4.7914
4.7860
4.7688
4.7620
4.7345
4.6649
4.6413
4.6340
4.6265
4.3884
3.7997
3.7963
3.7803
3.6142
3.5419
3.5341
3.5282
3.4990
3.4835
3.4797
3.3908
3.3773
3.3672
1.6443
1.1853
1.1726

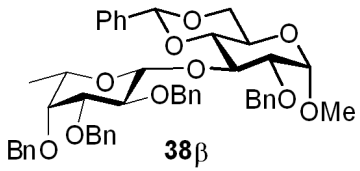

5.0217
4.9983
4.9469
4.9228
4.9132
4.8904
4.8444
4.8291
4.7914
4.7860
4.7688
4.7620
4.7345
4.7105
4.6649
4.6413
4.6340
4.6265
1.10
2.10
1.07
4.24
2.11
5.05
4.95
4.85
4.75
4.65
f1 (ppm)


3.7997
3.7963
3.7887
3.7803
3.6348
3.6142
3.5602
3.5527
3.5419
3.5341
3.5282
3.5179
3.4990
3.4835
3.4797
3.4643
3.3908
3.3773
3.3672
2.04
1.08
4.20
4.29
3.8
3.7
3.6
3.5
3.4
3.3
f1 (ppm)


Ph
O
O
O
O
O
OBn
BnO
OMe
BnO
OBn

**38**β


26.57
1.00
1.10
2.10
1.07
4.24
2.11
1.00
0.99
2.04
1.08
4.19
4.29
3.17
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)


Ph
O
O
O
O
O
OBn
BnO
OMe
BnO
OBn

**38**β


139.54
139.03
138.81
138.61
137.38
128.34
128.13
128.02
127.68
127.55
126.97
103.29
101.12
99.50
82.51
82.31
80.34
78.06
77.30
77.20
77.04
76.79
76.02
74.80
74.66
73.73
73.03
70.26
69.10
61.77
55.26
16.99
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


7.4217
7.4183
7.4077
7.4029
7.3656
7.3520
7.3432
7.3403
7.3307
7.3160
7.3067
7.2995
7.2841
7.2809
7.2687
7.2653
7.2572
7.2461
7.2426
7.2305
7.2045
7.1983
7.1956
7.1896
7.1840
7.1800
7.1761
5.5175
5.5101
5.4627
4.8849
4.8618
4.8377
4.8145
4.7281
4.7049
4.6765
4.6335
4.5933
4.5677
4.5443
4.4899
4.4827
4.2977
4.2108
4.0233
4.0159
3.9733
3.6806
3.6740
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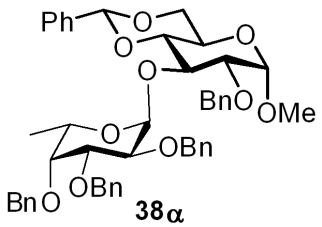
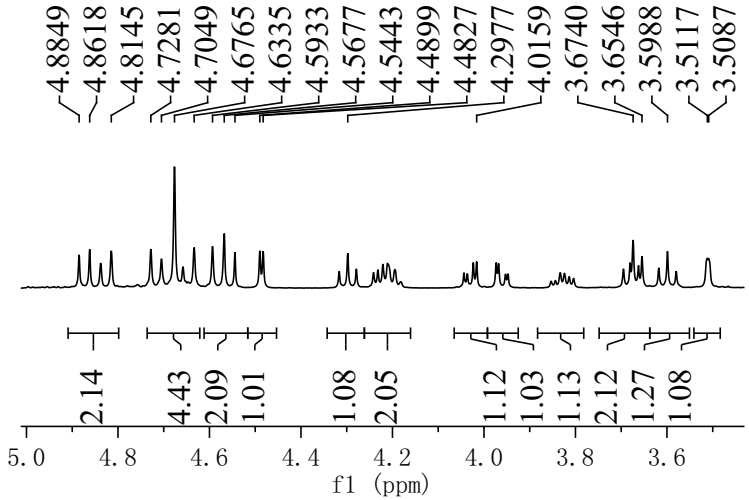
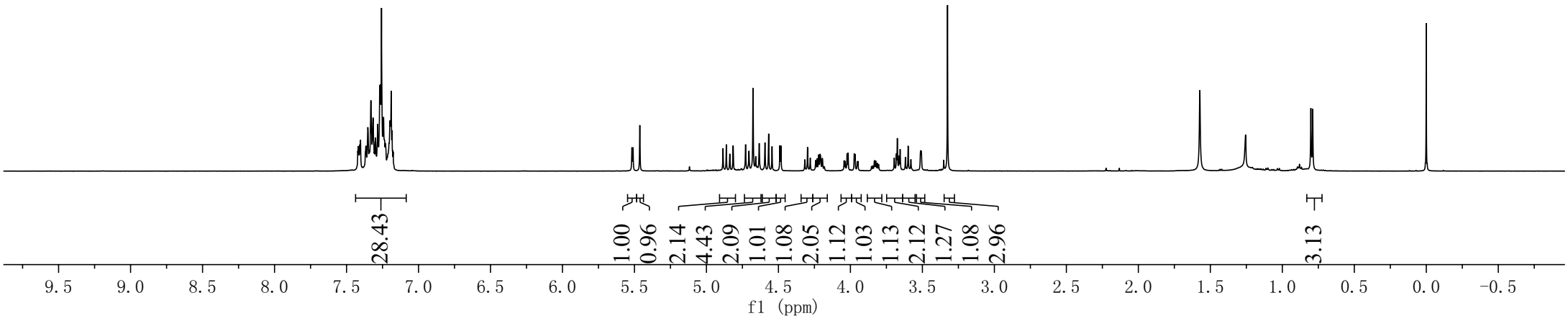
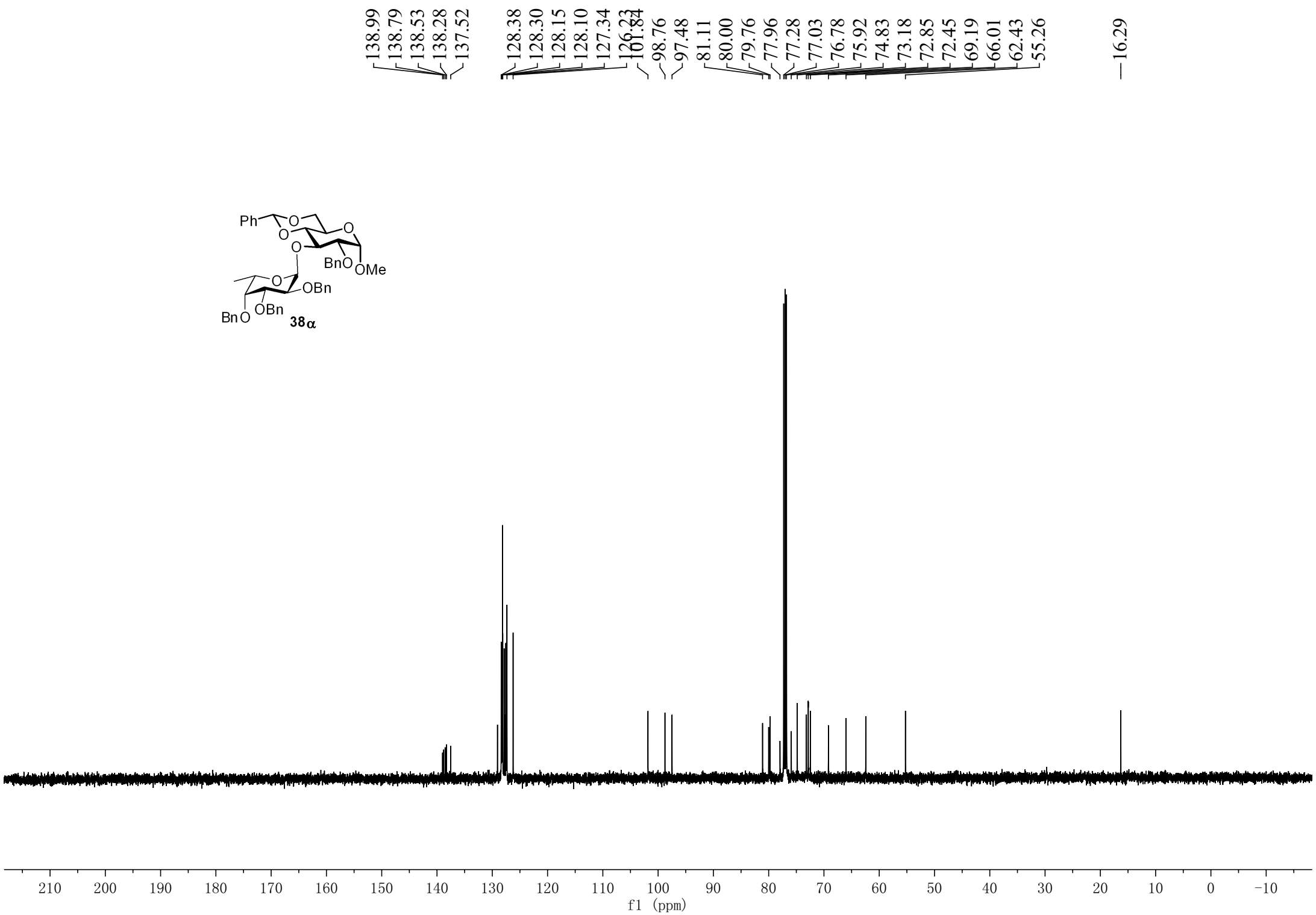
3.5087
3.3254
1.5731
0.8018
0.7889

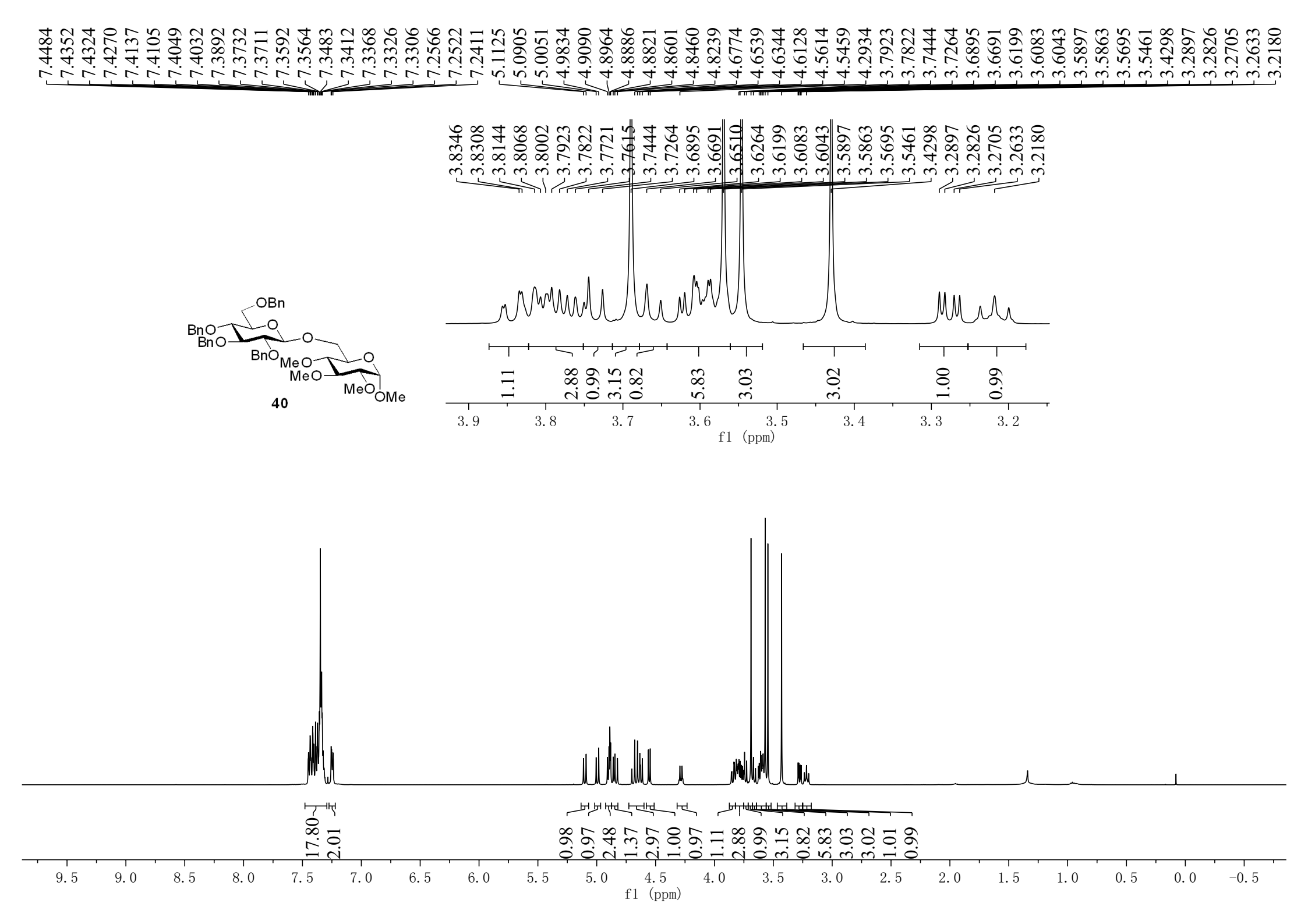

Ph
O
O
O
O
BnO
OMe
O
OBn
BnO
OBn

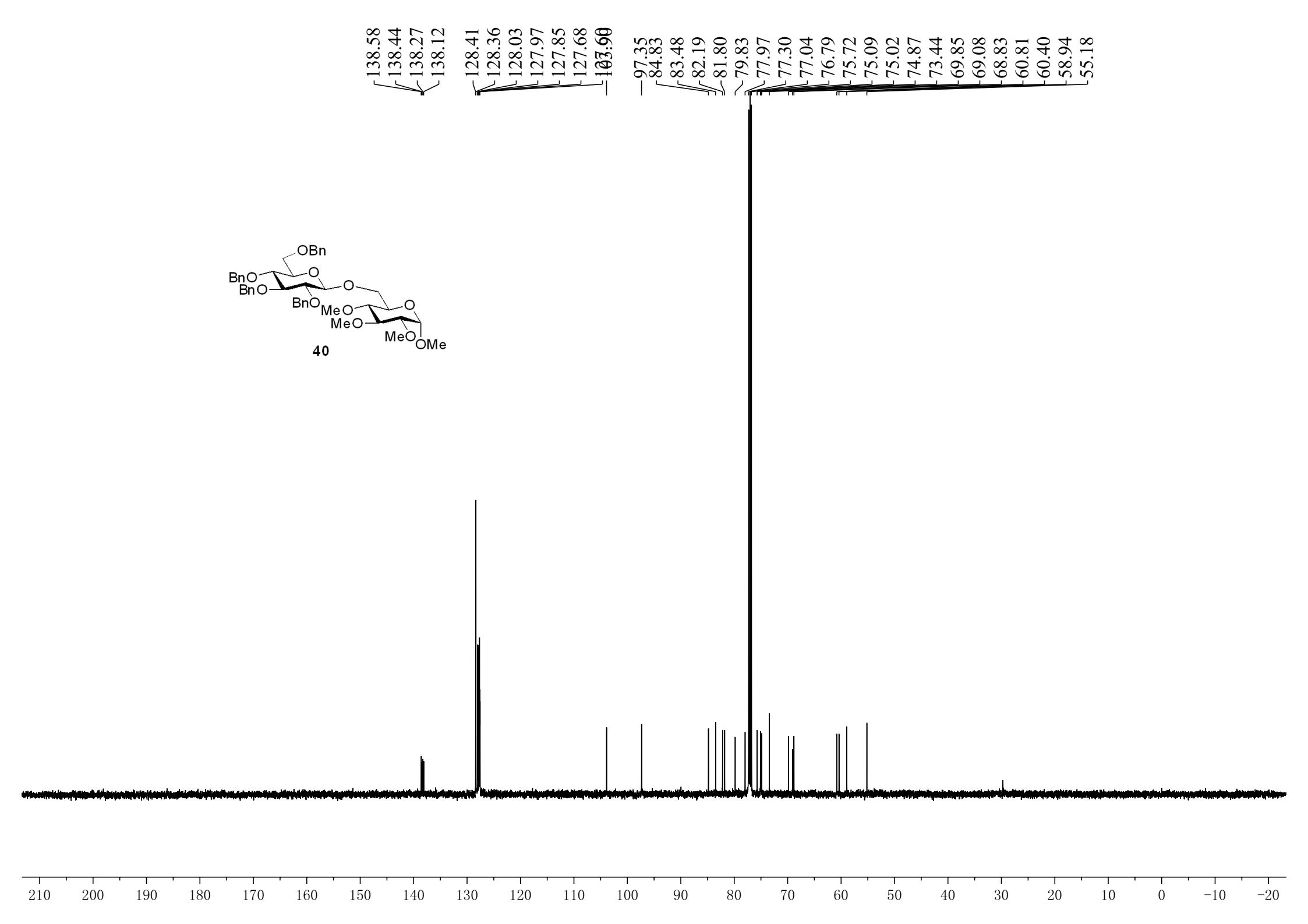
**38α**

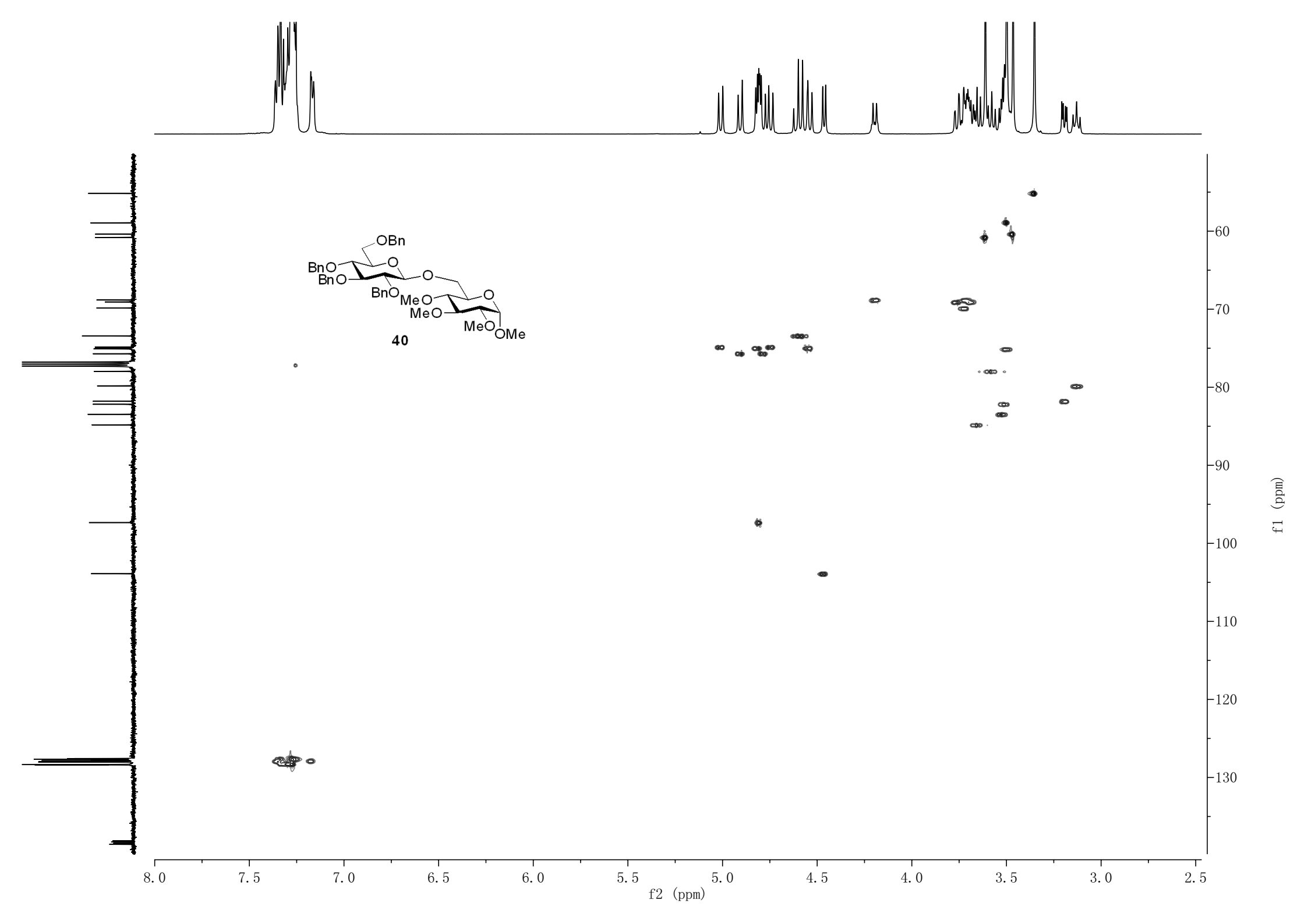

4.8849
4.8618
4.8145
4.7281
4.7049
4.6765
4.6335
4.5933
4.5677
4.5443
4.4899
4.4827
4.2977
4.0159
3.6740
3.6546
3.5988
3.5117
3.5087
2.14
4.43
2.09
1.01
1.08
2.05
1.12
1.03
1.13
2.12
1.27
1.08
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
f1 (ppm)

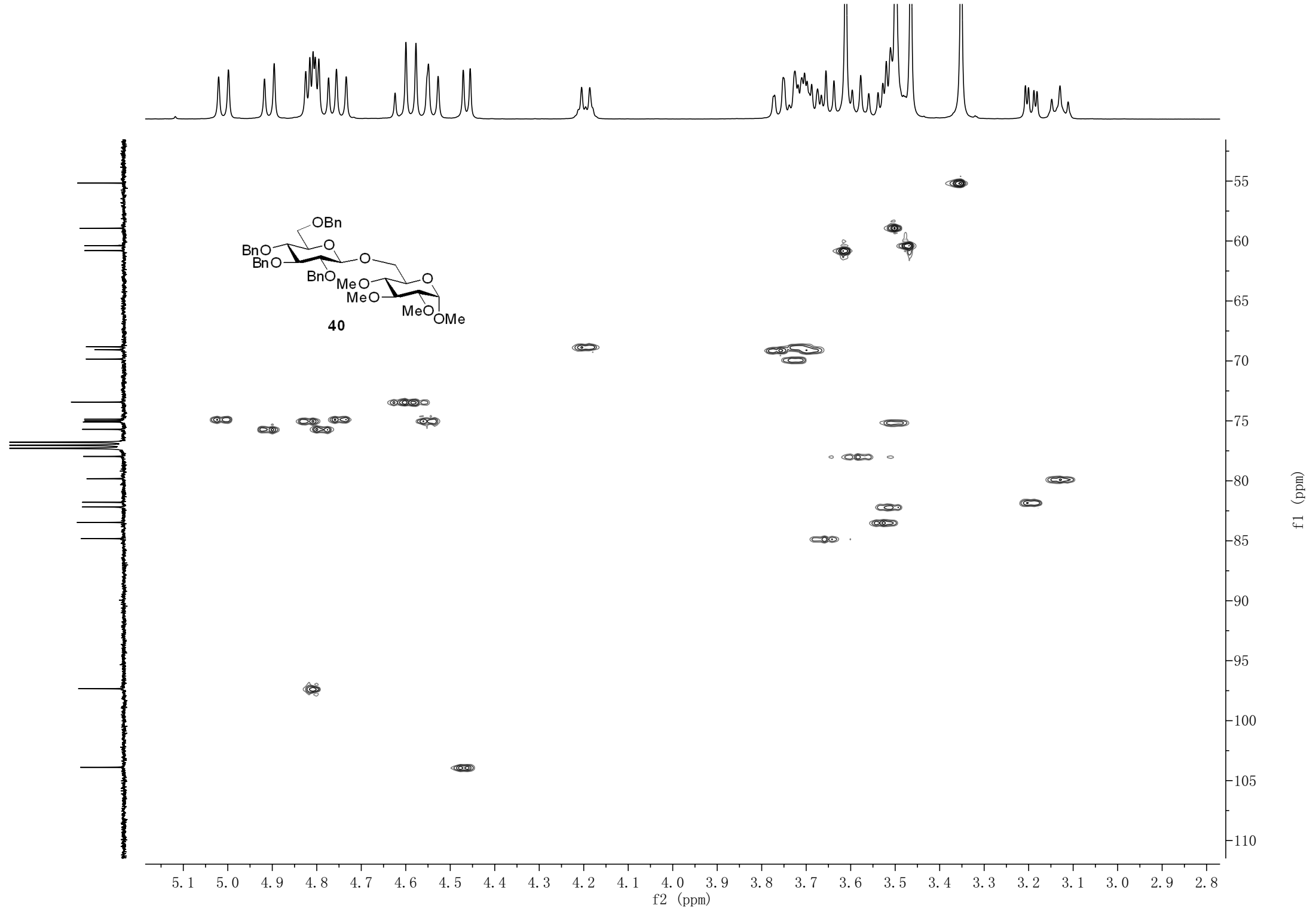

28.43
1.00
0.96
2.14
4.43
2.09
1.01
1.08
2.05
1.12
1.03
1.13
2.12
1.27
1.08
2.96
3.13
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
f1 (ppm)

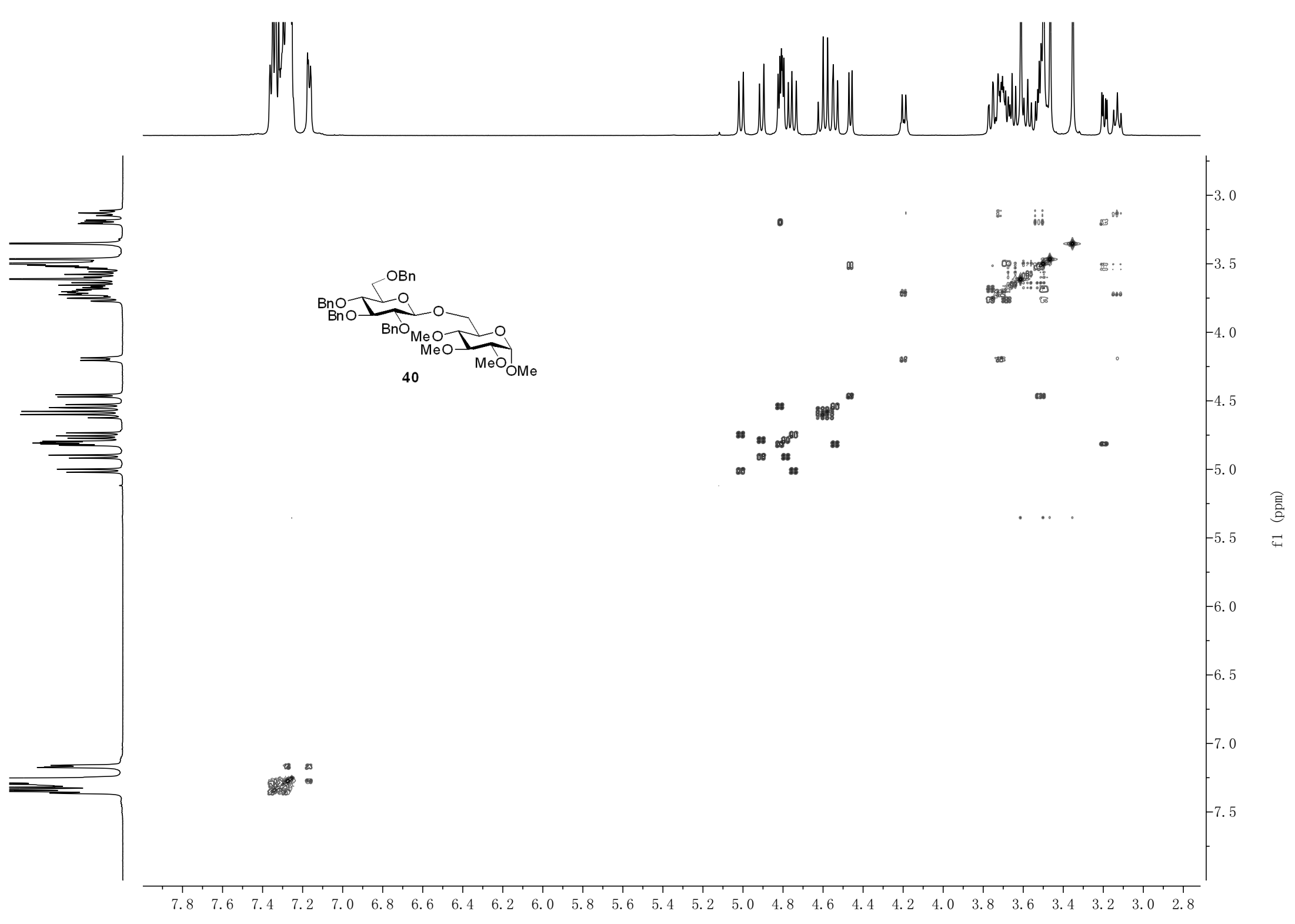

138.99
138.79
138.53
138.28
137.52
128.38
128.30
128.15
128.10
127.34
126.23
101.84
98.76
97.48
81.11
80.00
79.76
77.96
77.28
77.03
76.78
75.92
74.83
73.18
72.85
72.45
69.19
66.01
62.43
55.26
16.29
Ph
O
O
O
O
BnO
OMe
O
OBn
BnO
OBn
38α
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
f1 (ppm)

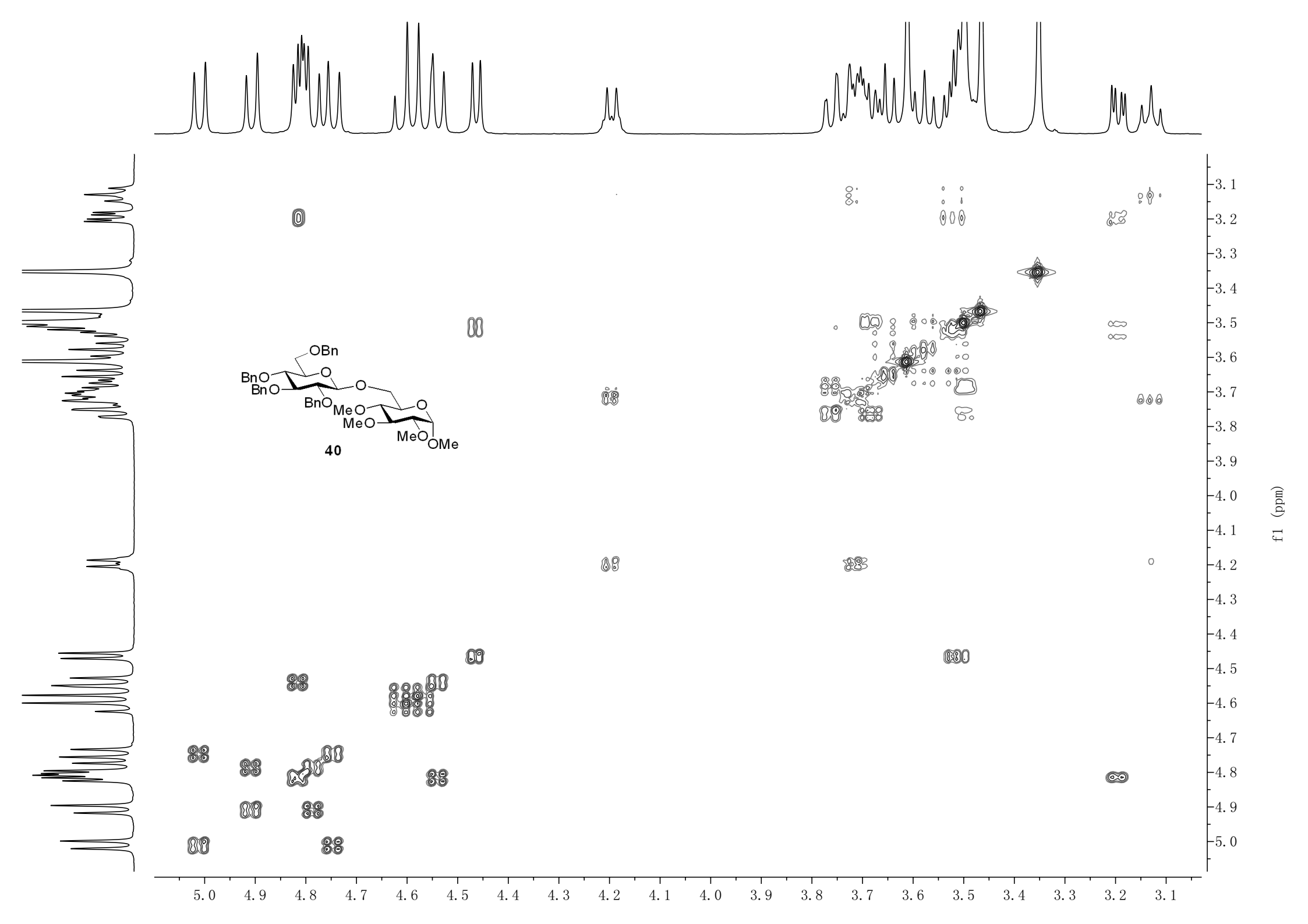

7.4484 7.4352 7.4324 7.4270 7.4137 7.4105 7.4049 7.4032 7.3892 7.3732 7.3711 7.3592 7.3564 7.3483 7.3412 7.3368 7.3326 7.3306 7.2566 7.2522 7.2411
5.1125 5.0905 5.0051 4.9834 4.9090 4.8964 4.8886 4.8821 4.8601 4.8460 4.8239 4.6774 4.6539 4.6344 4.6128 4.5614 4.5459 4.2934 3.7923 3.7822 3.7444 3.7264 3.6895 3.6691 3.6199 3.6083 3.6043 3.5897 3.5863 3.5695 3.5461 3.4298 3.2897 3.2826 3.2705 3.2633 3.2180
3.8346 3.8308 3.8144 3.8068 3.8002 3.7923 3.7822 3.7721 3.7615 3.7444 3.7264 3.6895 3.6691 3.6510 3.6264 3.6199 3.6083 3.6043 3.5897 3.5863 3.5695 3.5461 3.4298 3.2897 3.2826 3.2705 3.2633 3.2180
1.11 2.88 0.99 3.15 0.82 5.83 3.03 3.02 1.00 0.99
3.9 3.8 3.7 3.6 3.5 3.4 3.3 3.2
f1 (ppm)
OBn
BnO
BnO
BnO
MeO
MeO
MeO
OMe
40
17.80 2.01
0.98 0.97 2.48 1.37 2.97 1.00 0.97 1.11 2.88 0.99 3.15 0.82 5.83 3.03 3.02 1.01 0.99
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

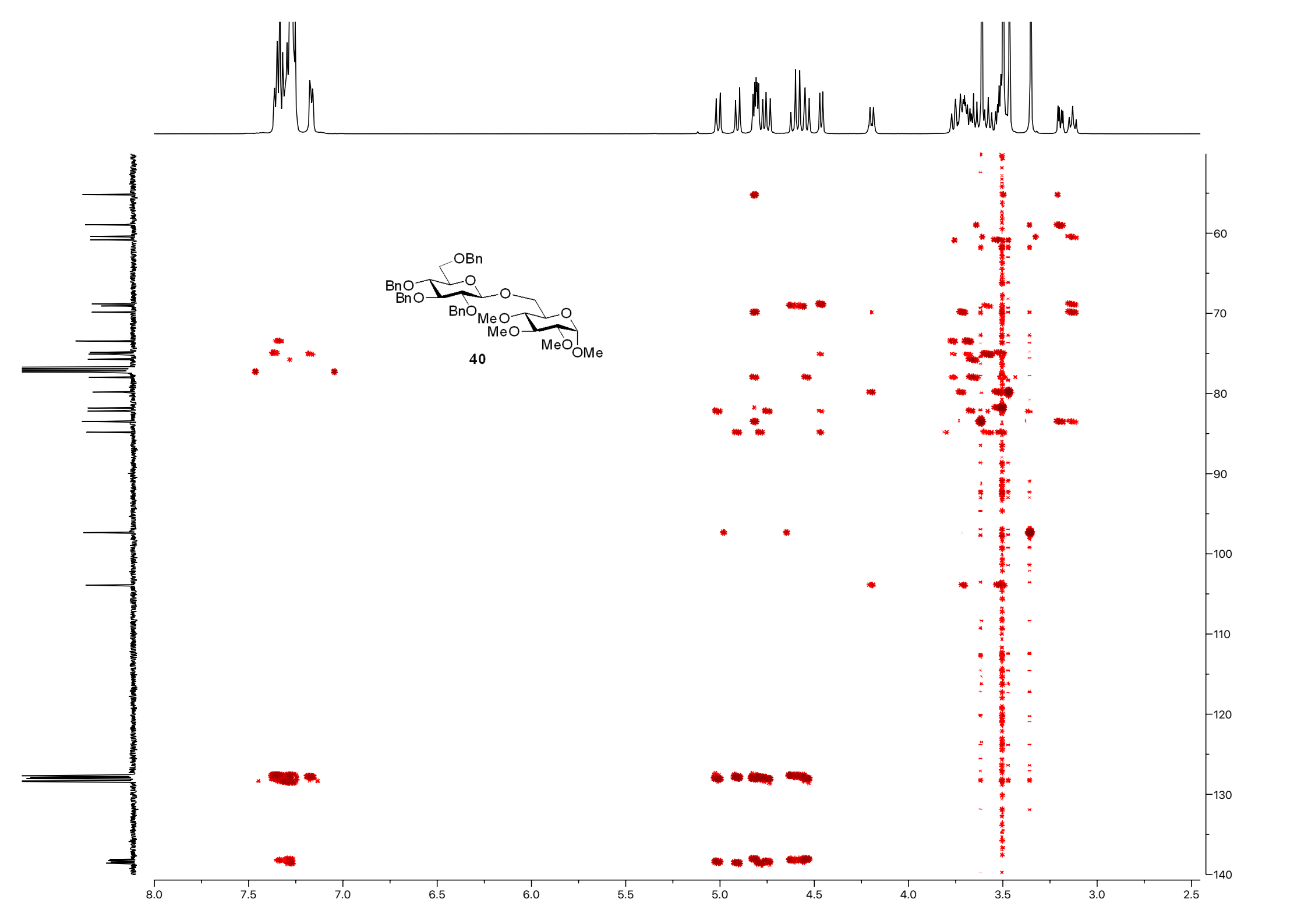

138.58
138.44
138.27
138.12
128.41
128.36
128.03
127.97
127.85
127.68
97.35
84.83
83.48
82.19
81.80
79.83
77.97
77.30
77.04
76.79
75.72
75.09
75.02
74.87
73.44
69.85
69.08
68.83
60.81
60.40
58.94
55.18
OBn
BnO
BnO
BnO
MeO
MeO
MeO
OMe
40
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20

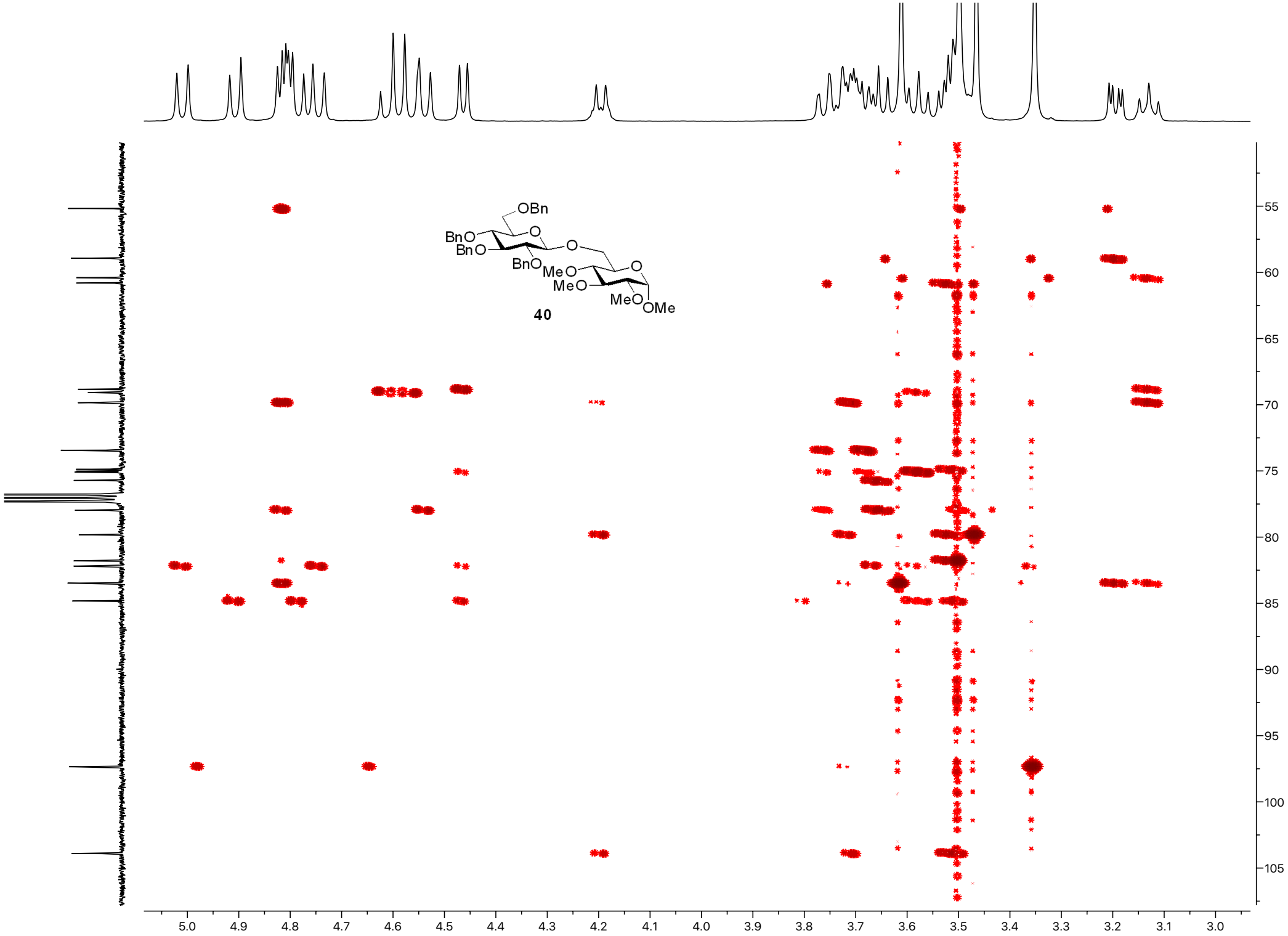

OBn
BnO
BnO
O
O
BnO
MeO
MeO
O
MeO
OMe
40
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
f2 (ppm)
60
70
80
90
100
110
120
130
f1 (ppm)


OBn
BnO
BnO
BnO
MeO
MeO
MeO
OMe
40
f2 (ppm)
f1 (ppm)


OBn
BnO
BnO
O
O
BnO
MeO
MeO
O
MeO
OMe
40
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
f1 (ppm)
7.8 7.6 7.4 7.2 7.0 6.8 6.6 6.4 6.2 6.0 5.8 5.6 5.4 5.2 5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8


OBn
BnO
BnO
BnO
MeO
MeO
MeO
OMe
40
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
f1 (ppm)


OBn
BnO
BnO
O
O
BnO
MeO
MeO
O
MeO
OMe
40
60
70
80
90
100
110
120
130
140
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5


OBn
BnO
BnO
BnO
MeO
MeO
MeO
OMe
40
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
55
60
65
70
75
80
85
90
95
100
105