CHAPTER-4

Synthesis of Photolabile Protecting Group (PPG) Protected Uronic Acid Building Blocks: Applications in Carbohydrate Synthesis with the Assistance of a Continuous Flow Photoreactor

4.1 Introduction

Uronic acid containing polysaccharides include glycosaminoglycans (GAGs), capsular polysaccharides of various bacteria, marine polysaccharides (Figure 4.1) are involved in many biological functions [1-2]. The synthesis of structurally well-defined carbohydrates is crucial for understanding the roles of glycans in biological systems [3].

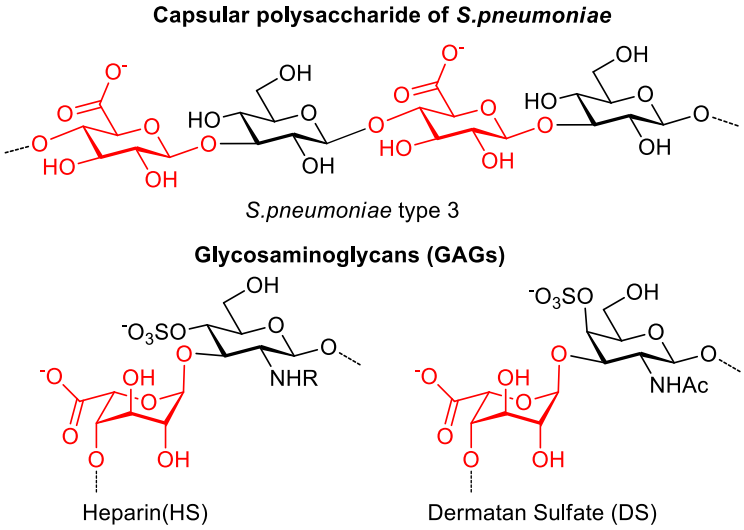
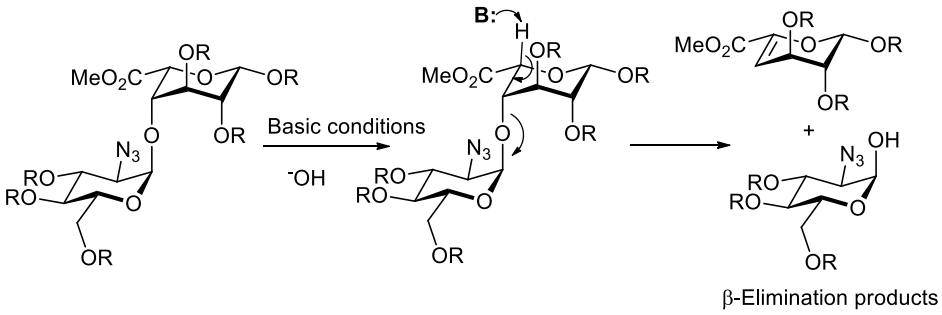


Figure 4.1 Examples of uronic acid containing polysaccharides

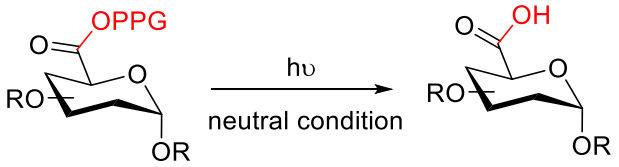
The synthesis of uronic acid containing oligosaccharides is often challenging since the protection and deprotection of the carboxylic acid requires special attention. The carboxylic acid is typically protected as methyl esters using hazardous diazomethane and cleaved at the end of oligosaccharide assembly by saponification under basic conditions (pH > 10). These strong basic conditions can sometimes lead to β-elimination or epimerization due to the acidic proton on C5 (Scheme 4.1) [4]. On the other hand, protection of carboxylic acid as benzyl ester was also demonstrated in oligosaccharides synthesis [5] while their

deprotection was affected using metal hydroxides (*i.e.* saponification) [5a, b] or Pd/C, H_2 (*i.e.* hydrogenolysis) [5c, d].



Scheme 4.1 *β*-Elimination under basic conditions

Photolabile protecting groups (PPGs) are appealing for organic synthesis; because photo-cleavage typically takes place at neutral conditions without any chemical reagents [6]. The protection of carboxylic acids using PPG esters may overcome the elimination or epimerization issues during oligosaccharide synthesis (Scheme 4.2). PPG-protected uronic acids have not been explored previously in carbohydrate synthesis.

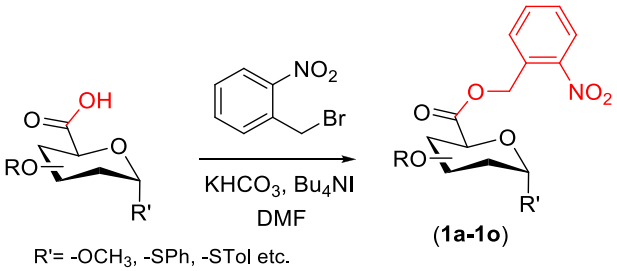


Scheme 4.2 Cleavage of PPG protected uronic acids

Photolabile protecting groups are well explored for natural product total syntheses, but their application to oligosaccharide synthesis remains less explored. Protecting group manipulations involving PPGs in batch photochemical carbohydrate syntheses might be low yielding [7]. However, continuous-flow photo-reactors overcome the major challenges associated with the use of batch reactors [8]. A higher surface-to-volume ratio and the proximity of the molecule to the UV lamp ensure effective irradiation of large volumes

while minimizing transmission versus distance constraints to provide good yields of the desired products. Photolabile protecting groups may be useful for carbohydrate synthesis when continuous flow photo-reactors are employed. The 2-nitro benzyl group is the most widely utilized among the photolabile protecting groups [5]. Our primary objective was the synthesis of 2-nitrobenzyl protected uronic acid building blocks and the cleavage of the PPG with the assistance of a continuous flow photoreactor.

As part of our carbohydrate synthesis program [9], we developed an efficient method for the preparation of various uronic acid building blocks using 1-chloro-1,2-benziodoxol-3(1H)-one and TEMPO at room temperature under neutral conditions [8a]. Using this method, we prepared various functionalized uronic acids and reacted them with 2-nitrobenzyl bromide in the presence of potassium bicarbonate and *tetra*-butylammonium iodide (Scheme 4.3).



Scheme 4.3 Synthesis of PPG protected uronic acids

4.2 Results and Discussion

4.2.1 Continuous flow photoreactor construction

The continuous flow photo-reactor (CFPR) was constructed with the help of M/s *Lelesil innovative systems, Mumbai, India.* The reactor (Figure 4.2) is composed of the main

photo-reactor unit within a photo safety cabinet, a digital lamp controller unit, a chiller and a peristaltic pump. The main unit of the system is composed of a stand, a quartz jacket with an inlet and outlet, a flexi coil (height 10 mm x 100 mm, diameter 4 mm) which is made up of a transparent FEP tube (Fluorinated Ethylene Propylene) obtained from M/s BOLA, Germany and a 250 W medium pressure mercury Lamp (MPMVL). This main unit is placed in a safety cabinet which is equipped with an exhaust fan and LED window. The inlet and outlet of the quartz jacket are connected to the chiller for cooling. The chiller circulates cold water (~5-8 ^{o}C) into the quartz jacket to neutralize the temperature generated by the Lamp. The peristaltic pump inlet is connected to the reagent bottle **B** (to store the solution to be photolyzed) and the outlet is connected to the flexi FEP coil. The upper side of the FEP tube is connected to another reagent bottle **A** to receive the photolyzed solution. The medium pressure mercury lamp is placed in the quartz jacket and connected to the digital lamp controller unit.

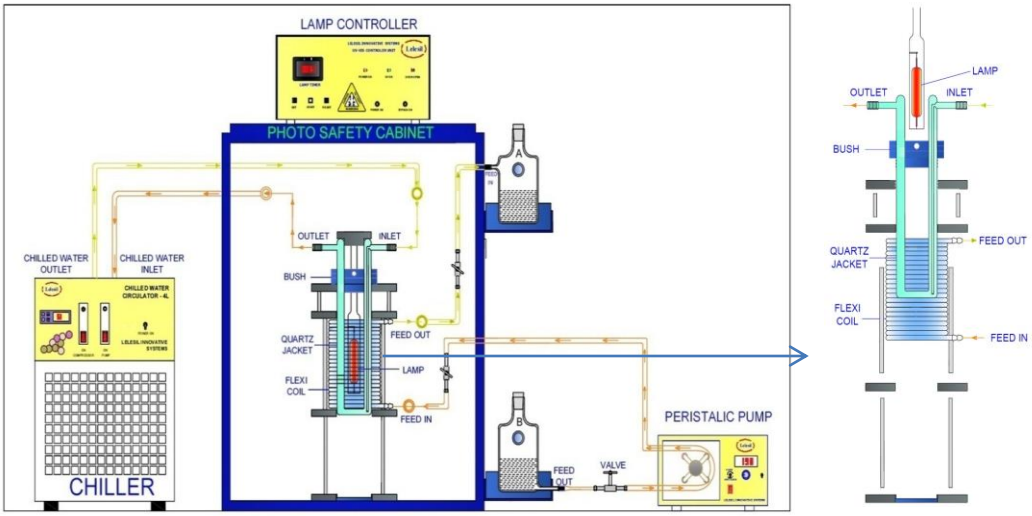
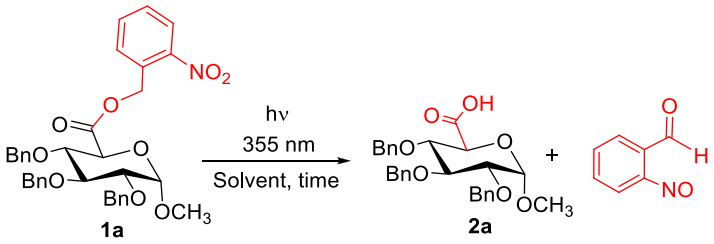


Figure 4.2 Schematic diagram of the continuous flow photo reactor

4.2.2 Cleavage of PPG in uronic acids using the continuous flow photoreactor

To find the best conditions, 2-nitrobenzyl protected *α*-methyl *tri-O*-benzyl glucuronic acid 1a was subjected for photolysis using the continuous flow photo-reactor (Table 4.1). The reaction was performed in polar solvents including methanol, THF, DCM, DMF, acetonitrile and 1, 4-dioxane (Table 4.1, entries 1-6).

Table 4.1 Optimization of photo-deprotection using flow and batch reactors.[a,b]



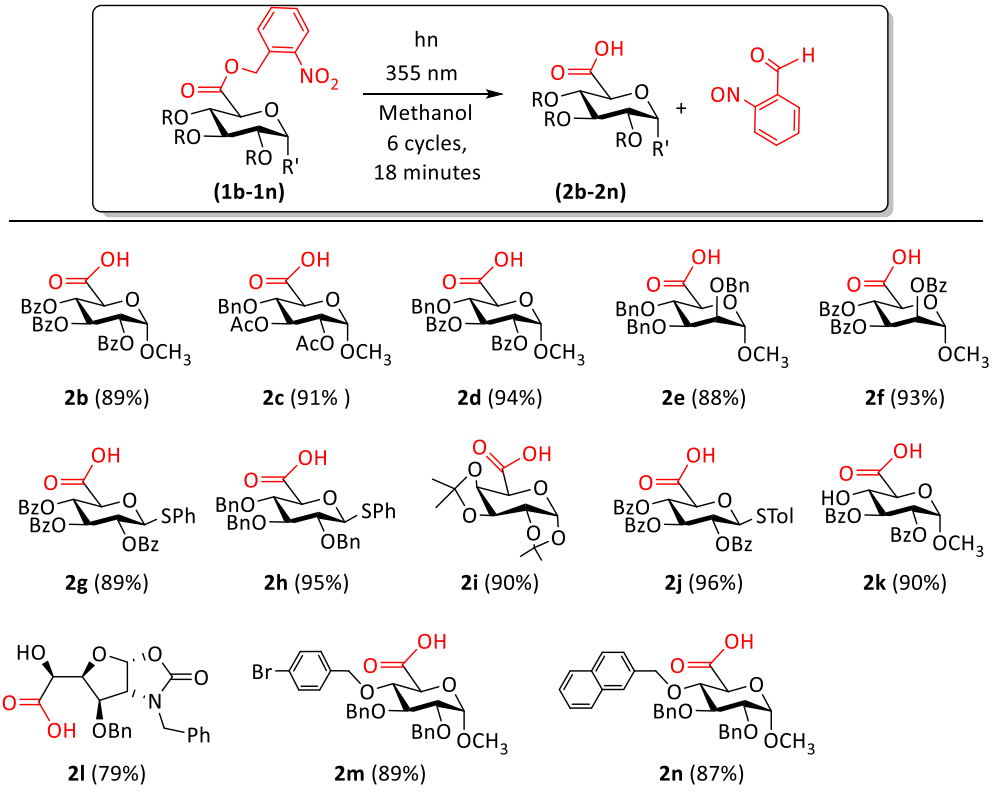
Entry	Solvent	No. of Cycle	Time (min)	Yield (%)
1	CH_3OH	1	3	60
2	THF	1	3	20
3	CH_2Cl_2	1	3	>5
4	DMF	1	3	19
5	CH_3CN	1	3	34
6	1,4-Dioxane	1	3	22
7	CH_3OH	3	9	78
8	CH_3OH	6	18	92
9	CH_3OH	9	27	89
10	CH_3OH	Batch Reactor	60	29
11	CH_3OH	Batch Reactor	120	64
12	CH_3OH	Batch Reactor	240	70

[a]0.005 molar solution of the PPG protected uronic acid was prepared in different solvents and stored in the reactor B. [b]Isolated yield.

A 0.005 M solution of the substrate was prepared in an appropriate solvent (50 mL) and added to reactor container B and circulated with the help of the peristaltic pump to the flexi coil. The peristaltic pump was kept 50 RPM which requires approx. 3 minutes to complete

one cycle of irradiation. The reaction yield was analyzed under irradiation for 3, 6 and 9 cycles respectively in methanol (Table 4.1, entries 7-9). The reaction was found to be most efficient in six cycles (= 18 min) which yielded 92% of the desired product resulting in the complete cleavage of PPG (Table 4.1, entry 8). In a batch reactor setup, only 29% desired product was obtained after one hour while 64% product was obtained after two hours (Table 4.1, entries 10-11). In fact, there was only a slight improvement in the yield in the batch reactor even after 4 h (Table 4.1, entry 12). Nevertheless, it is worthwhile to mention that the PPG protected uronic acid **1a** was found very stable in indoor lighting as well as in sunlight [10].

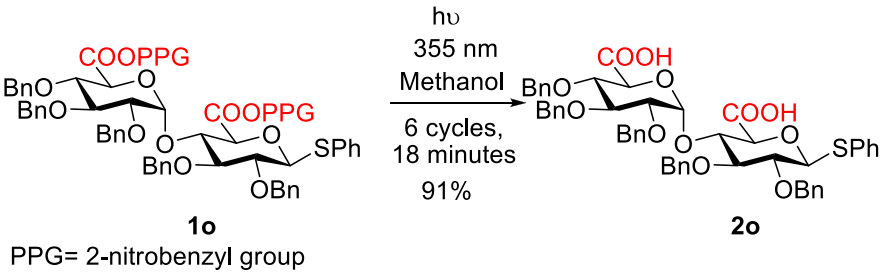
Table 4.2 Photo-deprotection of various uronic acid building blocks.[a,b]



[a]0.005 molar solution of the PPG protected uronic acid was subjected for photolysis with the flow rate 50 RPM. [b]Isolated yield.

With optimized conditions in hand, different PPG protected glucuronic acid, mannuronic acid, galacturonic acids equipped with different conventional protecting groups were subjected to photocleavage using the continuous flow photo-reactor (**Table 4.2**). The PPG was selectively cleaved in all the substrates as the desired products were obtained in quantitative yields. Other protecting groups such as benzyl, benzoyl, acetyl, acetonide, 4-bromobenzyl [11], 2-naphthylmethyl and carbamate were found to be very stable during the photo-cleavage of the 2-nitrobenzyl group.

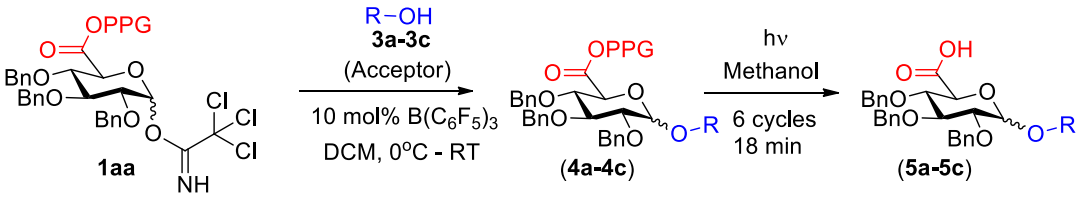
The deprotection protocol was applied to a disaccharide containing two photolabile protecting groups (**Scheme 4.4**). Still, the deprotection proceeds for the disaccharide as efficiently as for monosaccharides.

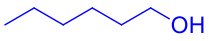
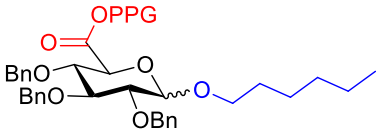
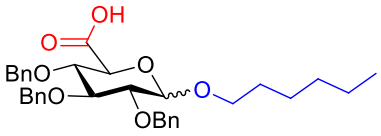
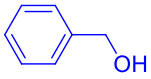
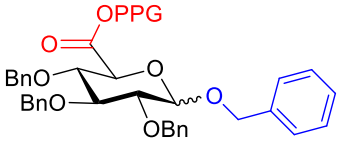
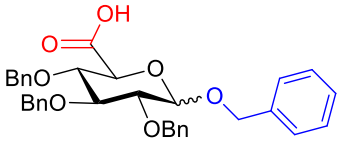
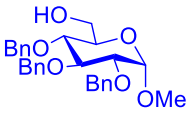
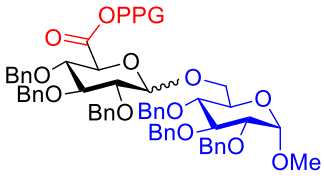
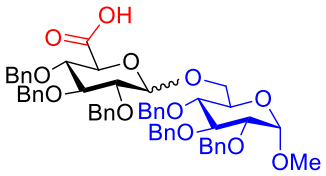


Scheme 4.4 Cleavage of photolabile protecting groups in disaccharides

To investigate the compatibility of PPGs with glycosylation conditions, the PPG protected glycosyl imidate **1aa** was used to glycosylate sugar and non-sugar acceptors (**3a-c**) in the presence of tris(pentafluorophenyl)borane (**Table 4.3**).[8c] These reactions yielded the desired glycosides (**4a-c**) in good yields as the PPG remained intact under these glycosylation conditions. The PPG in the glycosides **4a-c** were cleaved using the flow reactor to provide uronic acids **5a-c** in 90-94% yield.

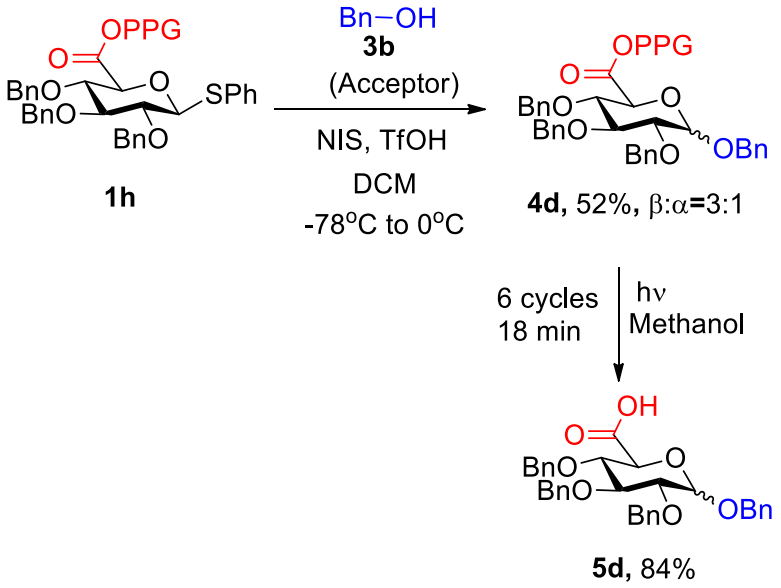
Table 4.3 Glycosylation followed by photo-deprotection of various uronic acid building blocks[a,b]



R−OH (Acceptor)	Glycosylation Product	Photolyzed product
 **3a**	 **4a,** 89%, β:α = >20:1	 **5a,** 90%
 **3b**	 **4b,** 85%, β:α = >20:1	 **5b,** 94%
 **3c**	 **4c,** 78%, β:α = ~3:2	 **5c,** 87%

Reaction conditions: Donor **1aa** (0.5 mmol), acceptor: **3a** and **3b** (3 equiv.), **3c** (1.2 equiv.), CH_2Cl_2 (8 mL), 10 mol% $B(C_6F_5)_3$; Mol. Sieves (4Å). [b]Isolated yield.

Further, we have investigated glycosylation of benzyl alcohol with PPG protected thioglycoside donor (**1h**) in the presence of NIS/TfOH in DCM (Scheme 4.5). To our delight, the desired glycosylated product **4d** was obtained in 52% yield. The compound **4d** was subsequently subjected to the photo-deprotection in flow reactor under optimized condition to obtain the uronic acid **5d** in 84% yield.



Scheme 4.5 Glycosylation with thioglycoside donor followed by photo-deprotection

4.3 Summary

The use of photolabile protecting group in uronic acid building blocks was investigated. The photolabile protecting group can be selectively cleaved in excellent yield in the presence of other protecting groups such as acetate, benzoate, acetonide, halobenzyl, 2-naphthyl methyl and carbamate. This protocol should prove useful for the synthesis of complex oligosaccharides.

4.4 Experimental Section

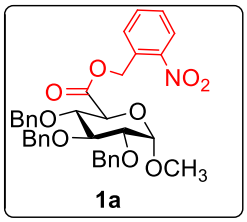
4.4.1 General procedure for synthesis of uronic acid esters with 2-nitrobenzyl bromide: (1a-1o)

To a stirred solution of appropriate uronic acid (0.5 equiv.) in dry DMF, $KHCO_3$(4.0 equiv.), Bu_4NI (0.2 equiv.) and 2-nitrobenzyl bromide (3 equiv.) were added under argon atmosphere. The resulting mixture was stirred for 16 h at room temperature. After completion, the reaction mixture was filtered on celite. The filtrate was washed with water

(2×50 mL) and dried over anhydrous sodium sulfate. The solvent was concentrated under reduced pressure to provide crude product which was purified by column chromatography on silica gel of 100-200 mesh size. Ethyl acetate/hexane was used as an eluent.

4.5 Analytical data of 2-nitrobenzyl protected uronic acid esters

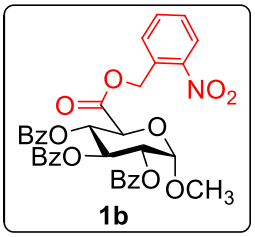
4.5.1 *α*-D-Glucopyranosiduronic acid, methyl-2,3,4-tris-*O*-(phenylmethyl)-2-nitrophenylmethyl ester (1a)



1a

Pale yellow viscous liquid (289 mg, 94%), R_f value =0.7 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1742, 1425, 1120, 1090 cm^{-1}. $[\alpha]_D^{24}$= -21.7 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.12 (dd, *J* = 5.9, 3.6 Hz, 1H), 7.53 (dd, *J* = 5.7, 3.5 Hz, 1H), 7.47–7.43 (m, 2H), 7.41–7.32 (m, 11H), 7.27 (dd, *J* = 4.8, 1.7 Hz, 2H), 7.21–7.19 (m, 2H), 5.60–5.53 (m, 2H), 5.02 (d, *J* = 10.9 Hz, 1H), 4.90–4.84 (m, 3H), 4.69 (t, *J* = 7.7 Hz, 2H), 4.60 (d, *J* = 11.0 Hz, 1H), 4.34 (d, *J* = 10.0 Hz, 1H), 4.07 (t, *J* = 9.3 Hz, 1H), 3.84 (t, *J* = 9.5 Hz, 1H), 3.64 (dd, *J* = 9.6, 3.5 Hz, 1H), 3.47 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 169.1, 147.1, 138.4, 137.9, 133.9, 131.5, 128.7, 128.6, 128.5, 128.4, 128.4, 128.3, 128.2, 128.1, 128.0, 127.7, 127.7, 125.0, 98.8, 81.5, 79.4, 79.3, 75.9, 75.0, 73.6, 70.3, 63.7, 55.7. HRMS: Calc. for $C_{35}H_{36}NO_9[M+H]^+$:614.2390, Obser.614.2397.

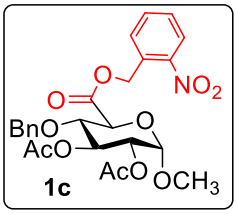
4.5.2 *α*-D-Glucopyranosiduronic acid, methyl-2,3,4-tri-O-benzoyl-2-nitro phenylmethyl ester(1b)



1b

Pale yellow viscous liquid (304 mg, 91%); R_f value =0.4 in 30% EtOAc/ Hexane.IR: ν_{max}(neat) 1750, 1719, 1420, 1099 cm^{-1}.$[\alpha]_D^{24}$= +93.0 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.16–8.10 (m, 2H), 8.00 (dd, *J* = 17.6, 9.4 Hz, 3H), 7.77 (d, *J* = 7.7 Hz, 1H), 7.70 (dd, *J*= 11.9, 5.7 Hz, 2H), 7.62–7.33 (m, 11H), 5.86 (t, *J* = 9.6 Hz, 1H), 5.73 (d, *J* = 6.8 Hz, 1H), 5.51–5.41 (m, 1H), 5.26 (m, 2H), 5.00 (s, 1H), 4.60 (d, *J* = 10.1 Hz, 1H), 4.49 (d, *J* = 9.8 Hz, 1H), 4.22 (m, 1H), 3.52 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 169.0, 167.5, 166.8, 165.9, 147.4, 136.8, 134.1, 134.0, 133.6, 133.5, 133.4, 133.4, 131.3, 129.9, 129.9, 129.8, 129.4, 129.2, 129.0, 129.0, 128.9, 128.9, 128.4, 128.4, 128.4, 127.9, 125.2, 125.0, 97.5, 72.6, 71.0, 70.6, 64.1, 62.5, 56.0. HRMS: Calc. for $C_{35}H_{30}NO_{12}[M+H]^+$: 656.1768, Obser. 656.1772.

4.5.3 *α*-D-Glucopyranosiduronic acid, methyl 2, 3-di-O-acetyl-4-O-benzyl-2-nitrophenylmethyl ester (1c)

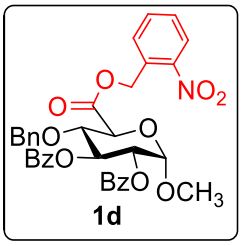


1c

Pale yellow viscous liquid (240 mg, 93%); R_f value = 0.36 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1745, 1735, 1410, 1215, 1090 cm^{-1}.$[\alpha]_D^{23}$= +44.5 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15–8.13 (m, 1H), 7.54–7.48 (m, 3H), 7.29–7.27 (m, 4H), 7.20–7.18 (m, 2H), 5.65–5.56 (m, 3H),

5.00 (d, *J* = 3.5 Hz, 1H), 4.90 (dd, *J* = 10.2, 3.6 Hz, 1H), 4.59 (s, 2H), 4.40 (d, *J* = 9.9 Hz, 1H), 3.96 (t, *J* = 9.6 Hz, 1H), 3.48 (s, 3H), 2.09 (s, 3H), 1.98 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.3, 169.7, 168.4, 147.2, 137.3, 133.9, 131.4, 128.8, 128.5, 128.4, 127.9, 127.8, 125.1, 97.4, 77.6, 74.7, 71.3, 70.9, 69.9, 63.9, 55.7, 20.8, 20.7. HRMS: Calc. for $C_{25}H_{28}NO_{11}$ $[M+H]^+$: 518.1662, Obser. 518.1668

4.5.4 *α*-D-Glucopyranosiduronic acid, methyl 2, 3-di-*O*-benzoyl-4-*O*-benzyl-2-nitrophenylmethyl ester (1d)

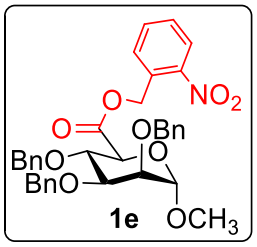


1d

Yellow viscous liquid (312 mg, 95%); R_f value = 0.42 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1736, 1716, 1290, 1088, 1375 cm^{-1} $[\alpha]_D^{24}$= +62.9 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.16 (dd, *J* = 8.0, 1.2 Hz, 1H), 8.01–7.98 (m, 4H), 7.60–7.48 (m, 5H), 7.40 (m, 4H), 7.16–7.08 (m, 5H), 6.11 (t, *J* = 9.7 Hz, 1H), 5.65 (q, *J* = 15.2 Hz, 2H), 5.26–5.21 (m, 2H), 4.63–4.58 (m, 2H), 4.55 (d, *J* = 9.9 Hz, 1H), 4.21 (t, *J* = 9.5 Hz, 1H), 3.50 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.4, 165.8, 165.4, 147.0, 136.9, 133.9, 133.3, 133.2, 131.4, 129.8, 129.6, 129.3, 128.8, 128.7, 128.4, 128.3, 128.2, 127.9, 127.8, 125.0, 97.5, 77.4, 74.7, 71.8, 71.7, 70.0, 63.8, 55.8. HRMS: Calc. for $C_{35}H_{32}NO_{11}$ $[M+H]^+$: 642.1975, Obser. 642.1970

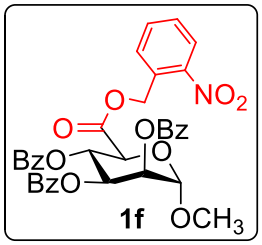
4.5.5 *α*-D-Mannopyranosiduronic acid, methyl-2, 3, 4-tris-*O*-(phenylmethyl)-2-

nitrophenylmethyl ester (1e)



Pale yellow viscous liquid (261 mg, 85%); R_f value = 0.5 in 20% EtOAc/ Hexane. IR: ν_{max}(neat) 1752, 1445, 1135, 1075 cm^{-1}. $[\alpha]_D^{24}$= +4.7 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.11–8.13 (m, 1H), 7.55-7.53 (m, 1H), 7.45–7.22 (m, 18H), 5.54 (q, *J* = 15.3 Hz, 2H), 4.94 (d, *J* = 2.9 Hz, 1H), 4.85-4.73 (m, 3H), 4.66-4.60 (m, 3H), 4.36–4.27 (m, 2H), 3.93 (dd, *J* = 8.1, 3.0 Hz, 1H), 3.80 (t, *J* = 3.1 Hz, 1H), 3.46 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.8, 147.1, 138.2, 138.0, 138.0, 133.8, 131.9, 128.5, 128.5, 128.3, 128.3, 127.8, 127.7, 127.6, 127.6, 125.0, 99.7, 78.7, 75.6, 74.5, 74.3, 72.9, 72.3, 72.0, 63.5, 55.6. HRMS: Calc. for $C_{35}H_{36}NO_9$ $[M+H]^+$: 614.2390, Obser. 614.2386

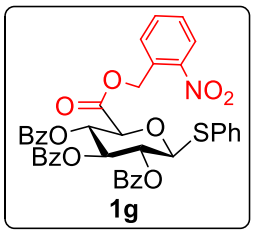
4.5.6 *α*-D-Mannopyranosiduronic acid, methyl 2, 3, 4-tri-O-benzoyl-2-nitrophenylmethyl ester (1f)



Pale yellow solid (291 mg, 89%); M.P:133-135 °C; R_f value = 0.6 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1755, 1729, 1414, 1040 cm^{-1}. $[\alpha]_D^{25}$= -60.2 [c 0.1, $CHCl_3$];^1H NMR (500 MHz, $CDCl_3$) δ 8.14–8.08 (m, 4H), 7.99–7.97 (m, 2H), 7.87 (d, *J* = 8.1 Hz, 2H), 7.63–7.58 (m, 2H), 7.54–7.51 (m, 1H), 7.46–7.37 (m, 7H), 7.30–7.27 (m, 2H), 6.14 (t, *J* = 10.1 Hz, 1H), 5.95 (dd, *J* = 10.1, 3.3 Hz, 1H), 5.74 (dd, *J* = 3.1, 1.7 Hz, 1H), 5.03 (s, 1H), 4.75 (dd, *J* = 12.1, 2.4 Hz,

1H), 4.54 (dd, *J* = 12.1, 4.4 Hz, 1H), 4.47–4.39 (m, 1H), 3.57 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.2, 165.5, 165.4, 133.4, 133.4, 133.1, 133.0, 129.8, 129.8, 129.8, 129.7, 129.7, 129.3, 129.1, 129.0, 128.6, 128.47, 128.3, 98.7, 70.4, 70.0, 68.7, 66.9, 62.9, 55.6. HRMS: Calc. for $C_{35}H_{30}NO_{12}$ $[M+H]^+$: 656.1768, Obser. 656.1770

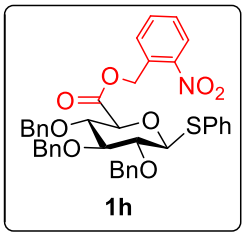
4.5.7 *β*-D-Glucopyranosiduronic acid, phenyl 2, 3, 4-tri-*O*-benzoyl-1-thio-2-nitrophenylmethyl ester (1g)



1g

Yellow viscous liquid (338 mg, 92%); R_f value = 0.48 in 30% EtOAc/ Hexane.IR: ν_{max}(neat) 1748, 1718, 1422, 1140 cm^{-1} .$[\alpha]_D^{24}$= +18.7 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (dd, *J* = 8.0, 1.5 Hz, 1H), 8.00–7.98(m, 2H), 7.86–7.82 (m, 4H), 7.58–7.28 (m, 17H), 5.94 (t, *J* = 9.4 Hz, 1H), 5.73 (t, *J* = 9.7 Hz, 1H), 5.65–5.51 (m, 3H), 5.11 (d, *J* = 9.9 Hz, 1H), 4.51 (d, *J* = 9.8 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.9, 165.6, 165.0, 164.9, 147.2, 133.8, 133.7, 133.4, 133.4, 133.3, 131.0, 130.9, 129.9, 129.8, 129.8, 129.0, 128.8, 128.7, 128.6, 128.5, 128.4, 128.4, 128.3, 125.0, 86.4, 77.2, 76.6, 73.5, 70.0, 69.9, 64.3. HRMS: Calc. for $C_{40}H_{32}NO_{11}S$ $[M+H]^+$: 734.1696, Obser. 734.1699

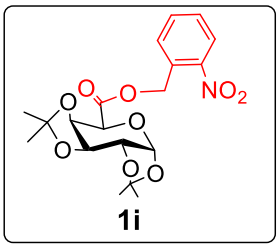
4.5.8 *β*-D-Glucopyranosiduronic acid, phenyl-2, 3, 4-tris-*O*-(phenylmethyl)-1-thio-2-nitrophenylmethyl ester (1h)



1h

Pale yellow viscous liquid (311 mg, 90%); R_f value = 0.6 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1743, 1520, 1145, 1130 cm^{-1}. $[\alpha]_D^{24}$= -2.9 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.18–8.10 (m, 1H), 7.56–7.20 (m, 22H), 5.53 (d, *J* = 5.3 Hz, 2H), 5.28 (d, *J* = 3.1 Hz, 1H), 4.94 (d, *J* = 10.8 Hz, 1H), 4.87–4.80 (m, 3H), 4.71 (d, *J* = 11.8 Hz, 1H), 4.61 (t, *J* = 10.4 Hz, 2H), 4.04 (t, *J* = 9.0 Hz, 1H), 3.84 (t, *J* = 9.2 Hz, 1H), 3.65 (dd, *J* = 9.1, 3.3 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.1, 147.0, 138.2, 137.7, 137.5, 133.9, 131.6, 128.6, 128.6, 128.5, 128.4, 128.3, 128.2, 128.1, 128.1, 127.9, 127.9, 127.8, 127.7, 125.0, 97.8, 91.7, 80.7, 79.2, 78.9, 75.7, 74.9, 73.5, 70.6, 63.6. HRMS: Calc. for $C_{40}H_{38}NO_8S$ $[M+H]^+$: 692.2318, Obser. 692.2315

4.5.9 *α*-D-galactopyranosiduronic acid- 1, 2, 3, 4-Di-*O*-isopropylidene-2-nitro phenylmethyl ester (1i)

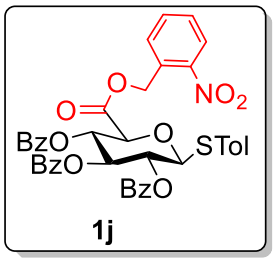


1i

Pale yellow viscous liquid (180 mg, 88%); R_f value = 0.5 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1747, 1465, 1235 cm^{-1}. $[\alpha]_D^{24}$= -62.4 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.2 Hz, 1H), 7.75 (d, *J* = 7.8 Hz, 1H), 7.64 (t, *J* = 7.6 Hz, 1H), 7.49 (t, *J* = 7.8 Hz, 1H), 5.75–5.67 (m, 11H), 5.31 (s, 1H), 4.68 (m, 2H), 4.56 (d, *J* = 2.0 Hz, 1H), 4.41 (dd, *J* = 4.9, 2.6 Hz, 1H), 1.55 (s, 3H), 1.46 (s, 3H), 1.36 (s,

3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 167.8, 147.2, 133.6, 132.0, 129.0, 128.6, 124.9, 110.0, 109.1, 96.5, 72.1, 70.7, 70.2, 68.6, 63.5, 25.9, 25.8, 24.7, 24.6. HRMS: Calc. for $C_{19}H_{24}NO_9$ $[M+H]^+$: 410.1451, Obser. 410.1448

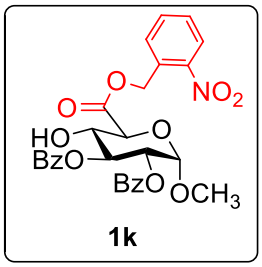
4.5.10 *β*-D-Glucopyranosiduronic acid, 4-Methylphenyl-2, 3, 4-*tri*-*O*-benzoyl-1-thio-2-nitrophenyl- methyl ester (1j)



1j

Pale yellow viscous liquid (347 mg, 93%); R_f value = 0.5 in 30% EtOAc/ Hexane.IR:ν_{max}(neat) 1738, 1720, 1255, 1445 cm^{-1} $[\alpha]_D^{24}$= +10.7 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05 (dd, *J* = 8.0, 1.4 Hz, 1H), 7.99–7.97 (m, 2H), 7.84–7.80 (m, 4H), 7.52 (dd, *J* = 10.5, 4.2 Hz, 2H), 7.46–7.38 (m, 8H), 7.32–7.25 (m, 5H), 7.13 (d, *J* = 7.9 Hz, 2H), 5.93 (t, *J* = 9.4 Hz, 1H), 5.69 (t, *J* = 9.7 Hz, 1H), 5.58 (m, 2H), 5.48 (t, *J* = 9.6 Hz, 1H), 5.04 (d, *J* = 9.9 Hz, 1H), 4.48 (d, *J* = 9.8 Hz, 1H), 2.35 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.9, 165.6, 165.0, 164.9, 147.2, 139.1, 134.4, 133.7, 133.4, 133.4, 133.3, 131.0, 129.8, 129.8, 129.8, 129.8, 129.1, 129.0, 128.8, 128.6, 128.5, 128.4, 128.4, 128.3, 126.8, 125.0, 86.5, 76.6, 73.5, 70.0, 69.9, 64.2, 21.2. HRMS: Calc. for $C_{41}H_{34}NO_{11}S$ $[M+H]^+$: 748.1853, Obser. 748.1855.

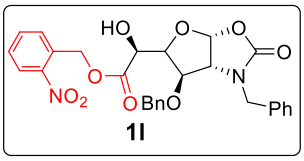
4.5.11 *α*-D-Glucopyranosiduronic acid, methyl-2-nitrophenylmethyl ester-2, 3-dibenzoate (1k)



1k

Pale yellow viscous liquid (177 mg, 83%); R_f value = 0.5 in 40% EtOAc/ Hexane. IR: ν_{max}(neat) 3250, 1756, 1718, 1360, 1180, 1080 cm^{-1} $[\alpha]_D^{23}$= +134.5 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.13 (d, *J* = 8.2 Hz, 1H), 8.00–7.95 (m, 4H), 7.73–7.68 (m, 1H), 7.50 (dd, *J* = 4.5, 2.9 Hz, 3H), 7.36 (t, *J* = 7.5 Hz, 5H), 5.89–5.85 (m, 1H), 5.71 (q, *J* = 15.0 Hz, 2H), 5.25 (s, 2H), 4.49 (d, *J* = 9.9 Hz, 1H), 4.22 (t, *J* = 9.6 Hz, 1H), 3.49 (s, 3H), 3.47 (d, *J* = 0.9 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.9, 165.7, 162.5, 147.1, 133.9, 133.3, 133.2, 131.3, 129.7, 129.7, 129.5, 129.1, 128.8, 128.8, 128.7, 128.3, 128.2, 125.0, 97.4, 72.4, 71.0, 70.6, 70.5, 63.9, 55.8. HRMS: Calc. for $C_{28}H_{26}NO_{11}$ $[M+H]^+$: 552.1506, Obser. 552.1501

4.5.12 (2S)-2-nitrobenzyl-2-((3aR, 6R, 6aR)-1-benzyl-6-(benzyloxy)-2-oxohexa hydrofuro [3, 2-d]oxazol-5-yl)-2-hydroxyacetate (1l)

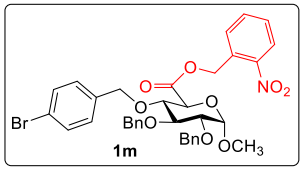


1l

Pale yellow viscous liquid (214 mg, 80%); R_f value = 0.6 in 50% EtOAc/ Hexane. IR: ν_{max}(neat) 3355, 1762, 1751, 1290, 1120, 1075 cm^{-1}. $[\alpha]_D^{24}$= -48.6 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.10–8.09(m, 1H), 7.52–7.45 (m, 3H), 7.41–7.38 (m, 3H), 7.29–7.27 (m, 4H), 7.24–7.22 (m, 2H), 7.12–7.10 (m, 2H), 6.22 (d, *J* = 5.5 Hz, 1H), 5.61 (m, 2H), 4.85 (d, *J* = 3.6 Hz, 1H), 4.69 (d, *J* = 15.1 Hz,

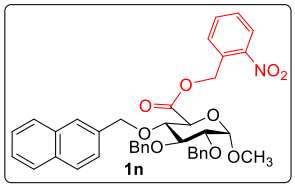
1H), 4.32 (s, 2H), 4.20–4.17 (m, 2H), 4.10 (d, *J* = 5.6 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.0, 156.3, 147.3, 136.2, 134.9, 133.8, 131.1, 129.2, 129.1, 129.0, 128.6, 128.6, 128.3, 128.2, 127.6, 125.0, 101.0, 80.0, 79.9, 77.2, 72.4, 63.8, 63.7, 47.6. HRMS: Calc. for $C_{28}H_{27}N_2O_9$ $[M+H]^+$: 535.1717, Obser. 535.1723

4.5.13 (2S,3S,4S,5R,6R)-2-nitrobenzyl-4,5-bis(benzyloxy)-3-(4-bromobenzyl oxy) -6-methoxytetra-hydro-2H-pyran-2-carboxylate (1m)



Pale yellow viscous liquid (325 mg, 94%); R_f value = 0.52 in 20% EtOAc/ Hexane. IR: ν_{max}(neat)1730, 1520, 1250, 1070, 565 cm^{-1} $[\alpha]_D^{24}$= -7.8 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.17–8.06 (m, 1H), 7.50–7.46 (m, 3H), 7.38–7.28 (m, 12H), 7.02 (d, *J* = 8.1 Hz, 2H), 5.57 (q, *J* = 15.0 Hz, 2H), 4.99 (d, *J* = 10.9 Hz, 1H), 4.83–4.76 (m, 3H), 4.69–4.66 (m, 2H), 4.50 (d, *J* = 11.3 Hz, 1H), 4.29 (d, *J* = 10.0 Hz, 1H), 4.02 (t, *J* = 9.3 Hz, 1H), 3.77 (t, *J* = 9.5 Hz, 1H), 3.61 (dd, *J* = 9.6, 3.5 Hz, 1H), 3.46 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 169.0, 147.3, 138.4, 137.8, 136.9, 133.7, 131.3, 131.3, 129.2, 128.8, 128.7, 128.5, 128.4, 128.1, 128.1, 127.9, 127.7, 125.1, 121.5, 98.8, 81.3, 79.4, 79.3, 75.8, 74.1, 73.6, 70.1, 63.7, 55.7. HRMS: Calc. for $C_{35}H_{34}BrNO_9$[M+H]$^+$: 691.1417, Obser.691.1415

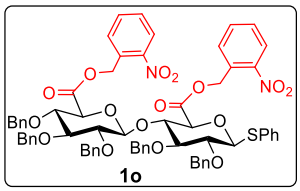
4.5.14 (2S,3S,4S,5R,6R)-2-nitrobenzyl-4,5-bis(benzyloxy)-6-methoxy-3-(naphtha- len-2-ylmethoxy)- tetrahydro-2H-pyran-2-carboxylate (1n)



1n

Pale yellow viscous liquid (309 mg, 93%); R_f value = 0.5 in 20% EtOAc/ Hexane. IR: ν_{max}(neat) 1735, 1515, 1268, 1077 cm^{-1}. $[\alpha]_D^{25}$= -8.9 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.9 Hz, 1H), 7.79–7.78 (m, 1H), 7.73–7.68 (m, 2H), 7.61 (s, 1H), 7.47–7.25 (m, 17H), 5.50 (m, 2H), 5.03 (dd, *J* = 11.0, 5.5 Hz, 2H), 4.87 (dd, *J* = 14.7, 11.6 Hz, 2H), 4.71 (m, 3H), 4.36 (d, *J* = 9.9 Hz, 1H), 4.10 (t, *J* = 9.2 Hz, 1H), 3.88 (t, *J* = 9.5 Hz, 1H), 3.66 (dd, *J* = 9.6, 3.4 Hz, 1H), 3.47 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 169.0, 147.0, 138.4, 137.9, 135.3, 133.7, 133.1, 132.9, 131.4, 128.5, 128.4, 128.1, 128.1, 128.0, 128.0, 127.8, 127.7, 127.6, 126.4, 126.0, 125.9, 125.7, 124.9, 98.8, 81.5, 79.4, 79.3, 75.9, 75.1, 73.6, 70.3, 63.7, 55.7. HRMS: Calc. for $C_{39}H_{37}NO_9$ $[M+H]^+$: 663.2468, Obser. 663.2471

4.5.15 β-D-Glucopyranosiduronic acid, phenyl-4-*O*-[6-methyl-2, 3, 4-*tris*-*O*-(phenylmethyl)-β-D-mannopyranuronosyl]-2, 3-*bis*-*O*-(phenylmethyl)-1-thio-2-nitrophenylmethyl ester (1o)

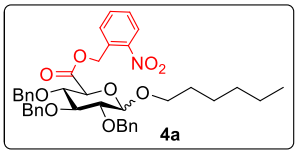


1o

Pale yellow viscous liquid (532 mg, 92%); R_f value = 0.5 in 30% EtOAc/ Hexane. IR: ν_{max}(neat) 1755, 1745, 1395, 1285, 1076 cm^{-1}. $[\alpha]_D^{24}$= +8.8 [c 0.1, $CHCl_3$];^1H NMR

(500 MHz, $CDCl_3$) δ 8.12-7.20 (m, 38H), 5.88 (s, 1H), 5.57 (m, 2H), 4.96–4.47 (m, 15H), 4.06 (t, J = 9.3 Hz, 1H), 3.91-3.83 (m, 3H), 3.64–3.61 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.7, 168.9, 147.1, 138.5, 138.0, 138.0, 137.1, 137.0, 134.1, 131.7, 128.8, 128.7, 128.7, 128.7, 128.6, 128.5, 128.2, 128.2, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 125.2, 102.5, 98.9, 81.2, 79.3, 77.4, 75.9, 75.3, 75.3, 74.1, 73.5, 73.0, 73.0, 72.3, 72.2, 71.1, 63.9. HRMS: Calc. for $C_{67}H_{63}N_2O_{16}S$ $[M+H]^+$: 1183.3898, Obser. 1183.3900

4.5.16 *β*-D-Glucopyranosiduronicacid, hexyl, 2, 3, 4-*tri*-*O*-benzyl-2-nitrophenyl methyl ester (4a)

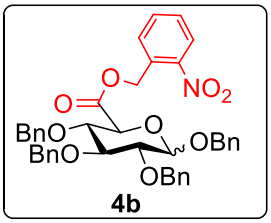


4a

Pale yellow solid (304 mg, 89%); M.P: 96-97 °C; R_f value = 0.7 in 30% EtOAc/ Hexane. β:α isomer (>20:1); IR: ν_{max}(neat) 1751, 1517, 1305, 1125 cm^{-1}. $[\alpha]_D^{24}$= -9.6 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.15–8.13 (m, 1H), 7.58–7.56 (m, 1H), 7.49–7.45 (m, 2H), 7.39–7.30 (m, 10H), 7.29–7.25 (m, 3H), 7.19 (dd, J = 6.8, 2.8 Hz, 2H), 5.63 (d, J = 15.3 Hz, 1H), 5.53 (d, J = 15.2 Hz, 1H), 4.97 (dd, J = 10.8, 9.6 Hz, 2H), 4.85 (dd, J = 16.8, 11.0 Hz, 2H), 4.76 (d, J = 10.9 Hz, 1H), 4.61 (d, J = 11.0 Hz, 1H), 4.53 (d, J = 7.7 Hz, 1H), 4.04–3.96 (m, 2H), 3.92 (t, J = 9.4 Hz,

1H), 3.73 (t, *J* = 9.1 Hz, 1H), 3.61-3.53 (m, 2H), 1.71–1.66 (m, 3H), 1.45–1.29 (m, 7H), 0.92 (dd, *J* = 9.5, 4.6 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.9, 147.1, 138.3, 138.2, 137.8, 133.8, 131.7, 128.6, 128.5, 128.4, 128.3, 128.1, 127.9, 127.8, 127.8, 127.7, 127.7, 125.0, 104.0, 83.9, 81.7, 78.9, 75.7, 74.9, 74.8, 74.5, 70.5, 63.6, 31.6, 29.6, 25.8, 22.5, 14.0. HRMS: Calc. for $C_{40}H_{46}NO_9$ $[M+H]^+$: 684.3173, Obser. 684.3168

4.5.17 *β*-D-Glucopyranosiduronic acid-1, 2, 3, 4-*tetra*-*O*-benzyl-2-nitrophenyl methyl ester (4b)

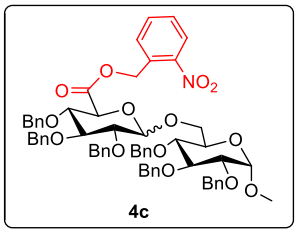


4b

Pale yellow powder. (293 mg, 85%); M.P: 124-126 °C; R_f value = 0.72 in 30% EtOAc/ Hexane. β:*α* isomer (>20:1); IR: ν_{max}(neat) 1775, 1480, 1310, 1095 cm^{-1}. $[\alpha]_D^{24}$= -22.9 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15–8.13(m, 1H), 7.59–7.57 (m, 1H), 7.48–7.45 (m, 2H), 7.41–7.26 (m, 19H), 7.21–7.18 (m, 2H), 5.59 (m, 2H), 5.02–4.93 (m, 3H), 4.84 (m, 2H), 4.73 (m, 2H), 4.64 (dd, *J* = 13.2, 9.3 Hz, 2H), 4.05 (d, *J* = 9.7 Hz, 1H), 3.96–3.93 (m, 1H), 3.74 (t, *J* = 9.0 Hz, 1H), 3.63 (dd, *J* = 9.0, 7.6 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 167.9, 147.2, 138.2, 138.1, 137.8, 137.0, 133.8, 131.6, 128.7, 128.6, 128.5, 128.4, 128.4, 128.4, 128.3, 128.1, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7,

127.7, 125.0, 102.8, 83.9, 81.8, 78.9, 75.7, 74.9, 74.6, 71.4, 63.7. HRMS: Calc. for $C_{41}H_{40}NO_9$ $[M+H]^+$: 690.2703, Obser. 690.2702

4.5.18 *α*-D-Glucopyranoside, methyl-6-*O*-[6-methyl-2,3,4-*tris*-*O*-(phenylmethyl) -D-glucopyranurono- syl]-2, 3, 4-*tris*-*O*-(phenylmethyl)-2-nitrophenylmethyl ester (4c)

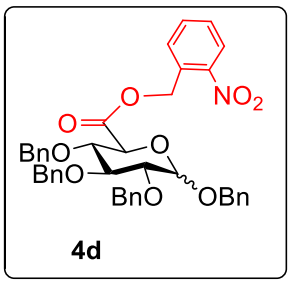


4c

Yellow solid (408 mg, 78%); M.P: 103-105 °C; R_f value = 0.5 in 30% EtOAc/ Hexane. β:*α* isomer (3:2); IR: ν_{max}(neat) 1762, 1487, 1254, 1082 cm^{-1}. $[\alpha]_D^{24}$= +12.1 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.12–8.09 (m, 1H), 7.45–7.39 (m, 2H), 7.38–7.24 (m, 29H), 7.18 (ddd, *J* = 7.7, 6.7, 1.7 Hz, 3H), 5.62–5.43(m, 2H), 5.03–4.92 (m, 3H), 4.88–4.52 (m, 10H), 4.44 (t, *J* = 8.8 Hz, 1H), 4.17 (dd, *J* = 10.8, 1.7 Hz, 1H), 4.04–3.97 (m, 2H), 3.91–3.78 (m, 3H), 3.71–3.46 (m, 4H), 3.37 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.2, 167.7, 147.1, 138.8, 138.4, 138.3, 138.3, 138.2, 138.1, 138.1, 138.0, 137.8, 133.8, 133.7, 131.6, 131.6, 128.6, 128.5, 128.5, 128.4, 128.4, 128.4, 128.3, 128.2, 128.1, 128.0, 128.0, 127.9, 127.9, 127.9, 127.8, 127.7, 127.7, 127.7, 127.6, 127.6, 127.6, 127.5, 127.5, 125.0, 124.9, 104.1, 98.0, 98.0, 97.8, 84.0, 82.1, 81.9, 81.5, 81.0, 80.1, 79.8, 79.5, 79.3, 78.8, 77.9, 77.7, 77.2, 75.7, 75.7, 75.6, 75.0, 74.9, 74.9, 74.8, 74.6, 73.3, 72.7, 70.4,

70.3, 69.8, 68.9, 66.7, 63.6, 63.5, 55.2. HRMS: Calc. for $C_{62}H_{64}NO_{14}$ $[M+H]^+$: 1046.4327, Obser. 1046.4329

4.5.19 D-Glucopyranosiduronic acid-1, 2, 3, 4-*tetra*-*O*-benzyl-2-nitrophenyl methylester (4d)



4d

White solid (165 mg, 52%); M.P: 123-125 °C; R_f value = 0.5 in 20% EtOAc/ Hexane. β:α isomer (3:1); IR: ν_{max}(neat) 1775, 1480, 1310, 1095 cm^{-1}. $[\alpha]_D^{24}$= -9.9 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.15–8.14 (m, 1H), 7.60–7.20 (m, 24H), 5.66–5.53 (m, 2H), 5.03–4.95 (m, 3H), 4.89–4.71 (m, 4H), 4.65 (dd, *J* = 12.6, 9.4 Hz, 2H), 4.07 (d, *J* = 9.7 Hz, 1H), 3.97 (t, *J* = 9.3 Hz, 1H), 3.75 (t, *J* = 9.0 Hz, 1H), 3.65–3.62 (m, 1H).^{13}C NMR (125 MHz, $CDCl_3$) δ 169.1, 168.0, 147.2, 138.5, 138.3, 138.1, 137.9, 137.8, 137.0, 136.7, 133.8, 131.6, 128.7, 128.7, 128.6, 128.6, 128.5, 128.4, 128.4, 128.4, 128.3, 128.3, 128.2, 128.1, 128.0, 128.0, 127.9, 127.8, 127.8, 127.8, 127.7, 125.1, 102.8, 96.1, 83.9, 81.8, 81.5, 79.4, 79.4, 78.9, 75.9, 75.7, 75.1, 74.9, 74.6, 73.2, 71.4, 70.6, 69.6, 63.7. Calc. for $C_{41}H_{40}NO_9$ $[M+H]^+$: 690.2703, Obser. 690.2705

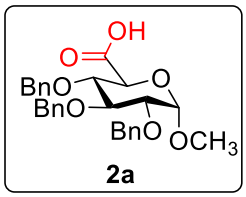
4.6 Experimental procedure for deprotection of photolabile 2-nitrobenzyl protecting group by using a continuous flow photoreactor

Approximately 0.005M solution of photolabile protected uronic acid building blocks were prepared in methanol and added to the reactor B. The solution was circulated with the help

of peristaltic pump to the flexi coil with a flow rate 50 RPM which required approx. 3 minutes for completing one cycle. Total six cycles were repeated after which the solvent was evaporated and purified through column chromatography.

4.7 Analytical data for various deprotected uronic acids

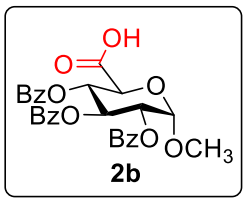
4.7.1 Methyl-2, 3, 4-tri-*O*-benzyl-*α*-D-glucopyranosiduronic acid (2a) [12]



2a

Colourless oily syrup (110 mg, 92%); R_f value =0.6 in 50% EtOAc/ Hexane. IR: ν_{max}(neat) 3482, 1712, 1120 cm^{-1}. $[\alpha]_D^{24}$= +4.4 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, DMSO-D_6) δ 7.40–7.22 (m, 16H), 4.91 (d, J = 3.4 Hz, 1H), 4.84 (d, J = 11.3 Hz, 1H), 4.75–4.66 (m, 4H), 4.58 (d, J = 11.0 Hz, 1H), 3.93 (d, J = 9.9 Hz, 1H), 3.79 (t, J = 9.3 Hz, 1H), 3.66–3.62 (m, 1H), 3.56 (dd, J = 9.6, 3.4 Hz, 1H), 3.34 (s, 3H).^{13}C NMR (125 MHz, DMSO-D_6) δ 170.9, 139.0, 138.8, 138.6, 128.7, 128.6, 128.6, 128.1, 128.1, 128.0, 127.9, 127.9, 127.8, 127.8, 98.0, 80.8, 79.6, 75.0, 74.5, 72.0, 70.4, 55.3.HRMS: Calc. for $C_{28}H_{31}O_7[M+H]^+$: 479.2070, Obser.479.2075.

4.7.2 Methyl-2, 3, 4-tri-*O*-benzoyl-*α*-D-glucopyranosiduronic acid (2b)

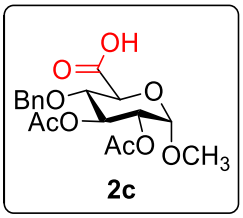


2b

Colourless Oily syrup (116 mg, 89%); R_f value =0.5 in 60% EtOAc/ Hexane. IR: ν_{max}(neat) 3545, 1718, 1710 cm^{-1}. $[\alpha]_D^{24}$= +62.2 [c 0.1, $CHCl_3$];^1H NMR (500 MHz, $CDCl_3$) δ 8.00–7.89 (m, 6H), 7.53 (q, J = 7.6 Hz, 2H), 7.46 (t, J = 7.4 Hz, 1H), 7.41-7.36 (m, 4H), 7.32 (t, J = 7.8 Hz, 2H), 6.20 (t, J = 9.8 Hz,

1H), 5.75 (t, *J* = 9.8 Hz, 1H), 5.37 (d, *J* = 3.6 Hz, 1H), 5.33 (dd, *J* = 10.1, 3.6 Hz, 1H), 4.66 (d, *J* = 10.1 Hz, 1H), 3.54 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 171.1, 165.7, 165.6, 165.4, 133.4, 133.4, 133.2, 129.9, 129.9, 129.7, 129.0, 128.8, 128.4, 128.4, 128.3, 97.4, 77.2, 71.4, 69.8, 68.0, 56.3.HRMS: Calc. for $C_{28}H_{25}O_{10}[M+H]^+$: 521.1448, Obser. 521.1446

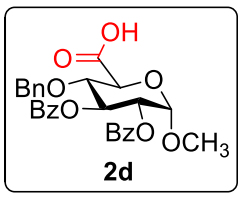
4.7.3 Methyl-2, 3-di-*O*-acetyl-4-benzyl-α-D-glucopyranosiduronic acid (2c)



2c

Colourless oily syrup (87 mg, 91 %); R_f value =0.5 in 50% EtOAc/Hexane. IR: ν_{max}(neat) 3353, 1735, 1719, 1082 cm^{-1}. $[\alpha]_D^{24}$= +53.6 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34–7.29 (m, 7H), 7.26–7.25 (m, 2H), 5.59–5.55 (m, 1H), 4.99 (d, *J* = 3.5 Hz, 1H), 4.88 (dd, *J* = 10.2, 3.6 Hz, 1H), 4.65 (m, 3H), 4.33 (d, *J* = 9.9 Hz, 1H), 3.89 (t, *J* = 9.5 Hz, 1H), 3.46 (s, 3H), 2.09 (s, 3H), 1.97 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 172.2, 170.3, 169.7, 137.2, 128.4, 128.0, 128.0, 97.3, 77.5, 74.7, 71.3, 70.8, 69.4, 55.8, 20.7, 20.7. HRMS: Calc. for $C_{18}H_{23}O_9[M+H]^+$: 383.1342, Obser. 383.1343

4.7.4 Methyl-2, 3-di-*O*-benzoyl-4-benzyl-α-D-glucopyranosiduronic acid (2d)

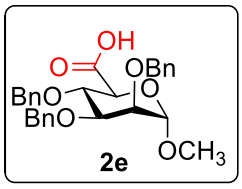


2d

Colourless oily liquid (119 mg, 94%); R_f value =0.6 in 50% EtOAc/ Hexane. IR: ν_{max}(neat) 3260, 1715, 1708, 1124 cm^{-1}. $[\alpha]_D^{24}$= +108.1 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10–8.08 (m, 4H), 7.62 (m, 2H), 7.49 (m, 4H), 7.26 (s, 5H),

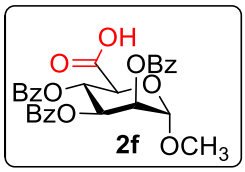
6.20 (t, *J* = 9.6 Hz, 1H), 5.35 (dt, *J* = 10.0, 3.6 Hz, 2H), 4.77 (m, 2H), 4.61 (d, *J* = 9.9 Hz, 1H), 4.28 (t, *J*= 9.5 Hz, 1H), 3.58 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 173.6, 166.0, 165.6, 136.9, 133.5, 133.3, 129.9, 129.7, 129.4, 128.8, 128.4, 128.3, 128.2, 128.0, 97.5, 77.4, 77.3, 77.1, 76.9, 74.8, 71.9, 71.7, 69.8, 55.9. HRMS: Calc. for $C_{28}H_{27}O_9[M+H]^+$: 507.1650, Obser.507.1648

4.7.5 Methyl-2, 3, 4-tri-*O*-benzyl-α-D-mannopyranosiduronic acid (2e) [12]



Colourless oily syrup (105 mg, 88%); R_f value =0.5 in 50% EtOAc/PE; IR: ν_{max} (neat) 3386, 1725, 1135 cm^{-1}.$[\alpha]_D^{23}$=+15.0 (c, 1.2 in CHCl3); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39–7.28 (m, 15H), 4.96 (s, 1H), 4.76 (m, 4H), 4.64 (d, *J* = 3.9 Hz, 2H), 4.31–4.21 (m, 2H), 3.93–3.91 (m, 1H), 3.80–3.79 (m, 1H), 3.46 (d, *J* = 1.3 Hz, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 174.1, 138.1, 138.0, 137.7, 128.4, 128.1, 127.9, 127.8, 127.7, 127.7, 127.6, 99.6, 78.5, 75.6, 74.5, 72.9, 72.4, 71.3, 55.7.HRMS: Calc. for $C_{28}H_{30}O_7Na$ $[M+Na]^+$: 501.1890, Obser.501.1893.

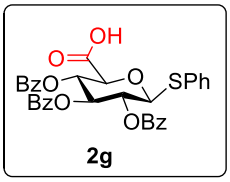
4.7.6 Methyl-2, 3, 4-tri-*O*-benzoyl-α-D-mannopyranosiduronic acid (2f)



Colourless oily syrup (121 mg, 93%); R_f value= 0.4 in 50% EtOAc/PE; IR: ν_{max}(neat) 3558, 1712, 1708 cm^{-1}. $[\alpha]_D^{24}$= -61.4 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10 (dd, *J*

= 8.2, 1.2 Hz, 2H), 7.98–7.97 (m, 2H), 7.87 (dd, *J* = 8.3, 1.2 Hz, 2H), 7.62 (t, *J*= 7.4 Hz, 1H), 7.54–7.45 (m, 4H), 7.39 (t, *J* = 7.7 Hz, 2H), 7.31 (t, *J* = 7.8 Hz, 2H), 6.05 (t, *J* = 9.5 Hz, 1H), 5.92 (dd, *J* = 9.6, 3.4 Hz, 1H), 5.69 (dd, *J* = 3.2, 2.5 Hz, 1H), 5.16 (d, *J* = 2.2 Hz, 1H), 4.69 (d, *J* = 9.4 Hz, 1H), 3.59 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.4, 165.5, 165.4, 165.3, 133.6, 133.4, 133.3, 129.9, 129.8, 129.7, 129.1, 129.0, 128.9, 128.6, 128.4, 128.3, 98.8, 69.8, 69.4, 69.3, 67.4, 56.2. HRMS: Calc. for $C_{28}H_{25}O_{10}$ $[M+H]^{+\beta}$: 521.1448, Obser. 521.1455

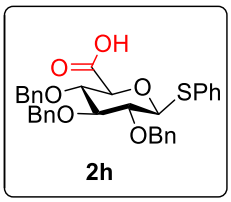
4.7.7 Phenyl-2, 3, 4-tri-*O*-benzoyl-1-thio-β-D-glucopyranosyduronic acid (2g)



2g

Colourless oily syrup (133 mg, 89%); R_f value = 0.53 in 50% EtOAc/PE; IR: ν_{max}(neat) 3440, 1712, 1705 cm^{-1}. $[\alpha]_D^{24}$= +23.3 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99–7.97 (m, 2H), 7.92–7.91 (m, 2H), 7.84–7.83 (m, 2H), 7.56–7.28 (m, 14H), 5.92 (t, *J* = 9.3 Hz, 1H), 5.73 (t, *J* = 9.6 Hz, 1H), 5.54 (t, *J* = 9.6 Hz, 1H), 5.11 (d, *J* = 9.9 Hz, 1H), 4.39 (d, *J* = 9.8 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ170.4, 165.6, 165.1, 164.9, 133.3, 133.3, 133.2, 131.7, 129.9, 129.8, 129.8, 129.2, 129.0, 129.0, 128.8, 128.4, 128.4, 128.3, 128.2, 86.5, 73.8, 70.3, 69.9, 66.2. HRMS: Calc. for $C_{33}H_{27}O_9S$ $[M+H]^+$: 599.1376, Obser. 599.1377

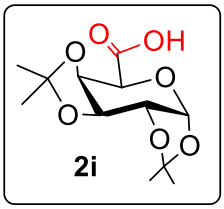
4.7.8 Phenyl-2, 3, 4-tri-*O*-benzyl-1-thio-β-D-glucopyranosyduronic acid (2h)



2h

Colourless oily syrup (132 mg, 95%); R_f value = 0.56 in 50% EtOAc/PE; IR: ν_{max} (neat) 3280, 1730, 1095 cm^{-1}. $[\alpha]_D^{24}$= -7.5 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ7.60–7.58 (m, 2H), 7.42–7.26 (m, 19H), 4.93 (d, *J* = 10.3 Hz, 1H), 4.88 (t, *J*= 7.8 Hz, 2H), 4.81–4.75 (m, 3H), 4.70 (d, *J* = 10.8 Hz, 1H), 4.01 (d, *J* = 9.3 Hz, 1H), 3.87 (t, *J* = 9.0 Hz, 1H), 3.77 (t, *J* = 8.6 Hz, 1H), 3.58 (dd, *J* = 9.6, 8.4 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.3, 138.0, 137.7, 137.3, 133.0, 132.3, 129.1, 128.5, 128.4, 128.4, 128.2, 128.1, 128.0, 127.9, 127.8, 88.1, 85.3, 80.2, 78.7, 77.5, 75.7, 75.4, 75.0. HRMS: Calc. for $C_{33}H_{33}O_6S$ $[M+H]^+$: 557.1998, Obser.557.2001

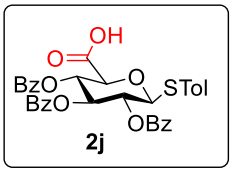
4.7.9 1, 2, 3, 4-Di-*O*-isopropylidene-α-D-galactopyranosiduronic acid (2i)



2i

Colourless viscous liquid (62 mg, 90%); R_f value = 0.6 in 50% EtOAc/ Hexane. IR: ν_{max} (neat) 3315, 1715 cm^{-1}. ^1H NMR (500 MHz, DMSO-d_6) δ 5.53 (d, *J* = 5.0 Hz, 1H), 4.65 (dd, *J* = 7.7, 2.5 Hz, 1H), 4.51 (dd, *J* = 7.7, 2.3 Hz, 1H), 4.40 (dd, *J* = 5.0, 2.5 Hz, 1H), 4.18 (d, *J* = 2.2 Hz, 1H), 1.43 (s, 3H), 1.32 (s, 3H), 1.28 (d, *J* = 3.3 Hz, 6H). ^{13}C NMR (125 MHz, DMSO-d_6) δ 169.3, 109.1, 108.5, 96.2, 71.9, 70.5, 69.9, 67.7, 26.2, 26.1, 25.1, 24.8. HRMS: Calc. for$C_{12}H_{19}O_7$ $[M+H]^+$: 275.1131, Obser. 275.1129

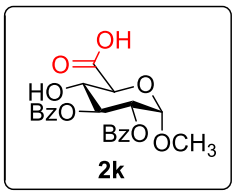
4.7.10 Tolyl-2, 3, 4-tri-*O*-benzoyl-1-thio-β-D-glucopyranosyduronic acid (2j)



2j

White solid (147 mg, 96%); M.P: 195-197 °C; R_f value = 0.5 in 50% EtOAc/ Hexane. IR: ν_{max} (neat) 3356, 1727, 1702 cm^{-1} $[\alpha]_D^{24}$= +12.6 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 8.00–7.98 (m, 2H), 7.92 (dd, *J* = 8.4, 1.2 Hz, 2H), 7.85–7.83 (m, 2H), 7.57–7.53 (m, 1H), 7.52–7.48 (m, 1H), 7.47–7.45 (m, 3H), 7.43–7.40 (m, 2H), 7.35 (dd, *J* = 10.8, 4.9 Hz, 2H), 7.31–7.28 (m, 2H), 7.16 (d, *J* = 7.9 Hz, 2H), 5.93 (t, *J* = 9.3 Hz, 1H), 5.70 (t, *J* = 9.6 Hz, 1H), 5.51–5.47 (m, 1H), 5.05 (d, *J* = 9.9 Hz, 1H), 4.42 (d, *J* = 9.7 Hz, 1H), 2.37 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.1, 165.7, 165.2, 164.9, 139.1, 134.3, 133.4, 133.4, 133.3, 129.9, 129.9, 129.8, 129.8, 129.1, 128.7, 128.6, 128.4, 128.4, 128.3, 127.0, 86.5, 75.9, 73.5, 70.0, 69.7, 21.2. HRMS: Calc. for$C_{34}H_{29}O_9S$ $[M+H]^+$: 613.1532, Obser. 613.1536

4.7.11 Methyl-2, 3-di-*O*-benzoyl-α-D-glucopyranosiduronic acid (2k)

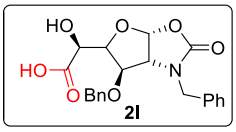


2k

Colourless oil (94 mg, 90%); R_f value = 0.55 in 50% EtOAc/PE; $[\alpha]_D^{24}$= +4.4 [c 0.1, $CHCl_3$]; IR: ν_{max} (neat) 3520, 3286, 1725, 1718, 1135 cm^{-1} $[\alpha]_D^{24}$= +151.7 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, MeOD-d_4) δ 8.00–7.98 (m, 2H), 7.91 (dd, *J* = 6.0, 4.7 Hz, 2H), 7.54 (t, *J* = 7.4 Hz, 2H), 7.42-7.37 (m, 4H), 5.83–5.78 (m, 1H), 5.20 (dd, *J* = 8.8, 2.7 Hz, 2H), 4.28 (d, *J* =

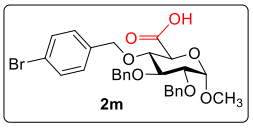
10.0 Hz, 1H), 4.09 (t, *J* = 9.7 Hz, 1H), 3.49 (s, 3H).^{13}C NMR (125 MHz, MeOD-d_4) δ 170.9, 166.1, 165.6, 133.2, 132.9, 129.6, 129.3, 129.2, 128.9, 128.1, 128.1, 97.5, 72.5, 71.7, 71.1, 69.8, 54.7. HRMS: Calc. for $C_{21}H_{21}O_9$ $[M+H]^+$: 417.1186, Obser.416.1190

4.7.12 2-(1-benzyl-6-(benzyloxy)-2-oxohexahydrofuro[3, 2-d]oxazol-5-yl)-2-hydroxy acetic acid (2l)



Colourless oily syrup (54 mg, 79%); R_f value = 0.43 in 60% EtOAc/PE; IR: ν_{max} (neat) 3306, 3120, 1711, 1302, 1135, 1070 cm^{-1}. $[\alpha]_D^{24}$= -49.4 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37–7.27 (m, 8H), 7.17 (t, *J* = 7.4 Hz, 3H), 6.14 (d, *J* = 5.0 Hz, 1H), 4.73 (s, 1H), 4.65 (d, *J* = 15.1 Hz, 1H), 4.40–4.31 (m, 2H), 4.17 (d, *J* = 3.3 Hz, 1H), 4.10 (s, 1H), 4.06–4.04 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ169.3, 156.8, 136.3, 134.7, 129.2, 128.6, 128.6, 128.3, 128.2, 127.8, 101.2, 79.5, 77.4, 77.1, 76.9, 72.6, 64.2, 47.5.HRMS: Calc. for $C_{21}H_{22}NO_7$ $[M+H]^+$: 400.1396, Obser. 400.1395

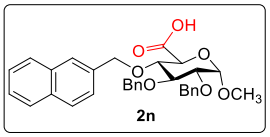
4.7.13 (2S,3S,4S,5R,6R)-4,5-bis(benzyloxy)-3-(4-bromobenzyloxy)-6-methoxy tetra hydro-2H-pyran-2-carboxylic acid (2m)



Colourless viscous liquid (124 mg, 89%); R_f value = 0.20 in 50% EtOAc/PE. IR: ν_{max} (neat) 3263, 1727, 1077, 585 cm^{-1};$[\alpha]_D^{24}$= -1.9 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40–7.28 (m, 12H), 7.09 (d, *J* = 8.3 Hz, 2H), 4.99 (d, *J* = 11.0

Hz, 1H), 4.83–4.74 (m, 3H), 4.66 (t, *J* = 7.3 Hz, 2H), 4.58 (d, *J* = 11.1 Hz, 1H), 4.24 (d, *J* = 10.0 Hz, 1H), 4.02 (t, *J* = 9.3 Hz, 1H), 3.70 (t, *J* = 9.5 Hz, 1H), 3.60–3.58 (m, 1H), 3.44 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 173.9, 138.3, 137.7, 136.6, 131.4, 129.5, 128.5, 128.4, 128.2, 128.1, 127.9, 127.8, 121.7, 98.6, 81.3, 79.2, 79.1, 75.9, 74.3, 73.6, 69.6, 55.8. HRMS: Calc. for $C_{28}H_{29}BrO_7$ $[M+H]^+$: 556.1097 , Obser. 556.1094

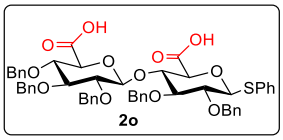
4.7.14 (2S,3S,4S,5R,6R)-4,5-bis(benzyloxy)-6-methoxy-3-(naphthalen-2-ylmethoxy) tetrahydro-2H-pyran-2-carboxylic acid (2n)



2n

Colourless viscous liquid (115 mg, 87%); R_f value = 0.20 in 50% EtOAc/PE; IR: ν_{max} (neat) 3215, 1712, 1120 cm^{-1}. $[\alpha]_D^{25}$= -6.2 [c 0.1, $CHCl_3$]; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.79–7.74 (m, 3H), 7.66 (s, 1H), 7.47–7.44 (m, 2H), 7.39–7.32 (m, 11H), 4.99 (dd, *J* = 26.3, 10.9 Hz, 2H), 4.86–4.78 (m, 3H), 4.67 (t, *J* = 7.9 Hz, 2H), 4.29 (d, *J* = 10.1 Hz, 1H), 4.07 (t, *J* = 9.3 Hz, 1H), 3.78 (t, *J* = 9.5 Hz, 1H), 3.62 (dd, *J* = 9.6, 3.4 Hz, 1H), 3.44 (s, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 173.3, 138.4, 137.8, 134.9, 133.2, 133.0, 128.5, 128.4, 128.2, 128.1, 128.1, 127.9, 127.9, 127.7, 127.6, 126.8, 126.0, 125.9, 125.8, 98.6, 81.4, 79.2, 79.2, 75.9, 75.3, 73.6, 69.6, 55.8. HRMS: Calc. for $C_{32}H_{32}O_7$ $[M+H]^+$: 528.2148, Obser. 528.2150

4.7.15 *β*-D-Glucopyranosiduronic acid, phenyl-2, 3-di-*O*-(benzyl)-1-thio-4-*O*-[2, 3, 4-tri-*O*-(benzyl)-*β*-D-glucopyranosiduronic acid] (2o)



2o

Colourless viscous liquid (207 mg, 91%); R_f value = 0.40 in 60% EtOAc/PE; IR: ν_{max} (neat) 3540, 3325, 1722, 1710, 1130 cm^{-1}. $[\alpha]_D^{24}$= +21.0 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 7.38–7.26 (m, 31H), 5.88 (s, 1H), 4.97–4.72 (m, 8H), 4.64–4.57 (m, 4H), 4.49 (t, *J* = 11.6 Hz, 2H), 4.06 (t, *J* = 9.3 Hz, 1H), 3.90 (m, 2H), 3.80 (t, *J* = 9.5 Hz, 1H), 3.62 (dd, *J* = 10.0, 3.8 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.8, 169.6, 138.4, 137.9, 137.6, 137.0, 136.9, 128.6, 128.6, 128.4, 128.4, 128.2, 128.1, 128.1, 128.0, 127.9, 127.9, 127.7, 127.7, 102.3, 98.4, 81.0, 79.1, 79.0, 77.3, 75.7, 75.2, 75.0, 73.8, 73.4, 72.7, 72.7, 72.2, 72.0, 70.5. HRMS: Calc. for $C_{53}H_{53}O_{12}S$ $[M+H]^+$: 913.3258, Obser. 913.3262

4.8 Procedure for synthesis of D-Glucopyranuronic acid, 2,3,4-tris-*O*-(phenyl methyl),2-nitrophenylmethyl ester, 1-(2,2,2-trichloroethanimidate) (1aa):

To a stirred solution of thioglycosides, **1h** (4 g, 5.78 mmol) in 40 ml acetone-water (9:1; v/v) was added N-bromosuccinamide (3.09 g, 17.35 mmol) and stirred for 1hour at room temperature. After that the reaction was quenched with $NaHCO_3$ and evaporated to dryness. The residue was dissolved in ethyl acetate (150 mL) and successively washed with sat. aq. $NaHCO_3$, water and brine. Organic layer was separated, dried using anhydrous sodium sulphate, evaporated in vacuo. The resulting residue was purified using silica gel column chromatography (2:1 hexane/ EtOAc) to give the corresponding hemiacetal 2.43 g

(70%) as viscous oil. The hemiacetal was dissolved in dry CH_2Cl_2 (20 mL) and cooled to 0 ^oC under argon atmosphere. DBU (0.2 ml,1.33 mmol) and trichloroacetonitrile (3.34 ml, 33.35 mmol) were added slowly and allowed to stir for 2h. After complete consumption of starting material, the reaction mixture was concentrated in vacuo and purified by silica gel column chromatography (30% EtOAc/ Hexane) with 1% added Et_3N to afford 2.23 g (90%) as colourless foam; α:β isomer (15.31:1); R_f value =0.6 in 20% EtOAc/ Hexane. ^1H NMR (500 MHz, $CDCl_3$) δ 8.74 (s, 1H), 8.13 (dd, *J* = 7.7, 1.7 Hz, 1H), 7.54-7.46 (m, 3H), 7.37–7.33 (m, 10H), 7.30-7.28 (m, 3H), 7.23 (dd, *J* = 6.6, 3.0 Hz, 2H), 6.61 (d, *J* = 3.5 Hz, 1H), 5.56 (m, 2H), 5.03 (d, *J* = 10.9 Hz, 1H), 4.91 (t, *J* = 11.2 Hz, 2H), 4.78 (m, 2H), 4.61 (m, 2H), 4.16 (t, *J* = 9.3 Hz, 1H), 3.97–3.87 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.1, 161.0, 147.1, 138.2, 137.6, 137.6, 133.9, 131.4, 128.7, 128.5, 128.5, 128.4, 128.4, 128.1, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 125.0, 94.0, 91.0, 80.8, 78.8, 78.5, 75.8, 75.3, 73.1, 72.7, 63.8.

4.9 General procedure for Glycosylation

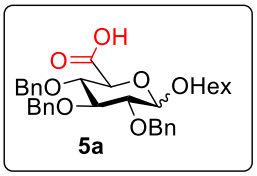
4.9.1 Glycosylation through Glycosyl Imidate donor: Donor **1aa** (0.5 mmol, 1equiv.) and acceptor (non- sugar 3 equiv. and sugar 1.2 equiv.) were dissolved in freshly dried CH_2Cl_2 (8 ml) and added to a flame dried round bottomed flask containing activated 4Å molecular sieves (300 mg) under argon atmosphere. The reaction mixture was then cooled to 0 ^oC to which the activator $B(C_6F_5)_3$ (10mol%) was added. The reaction was stirred further for 1.5 h allowing temperature to reach room temperature slowly. Quenching was done by the addition of Et_3N and filtered through Celite. The mixture was concentrated in

vacuo and the resulting residue was purified by silica gel column chromatography to afford the desired glycosylated product (78-89%).

4.9.2 Glycosylation through thioglycoside donor: Typical NIS/TfOH-promoted glycosylation procedure: A mixture of glycosyl donor (**1h**) (0.5 mmol, 1 equiv.), glycosyl acceptor (3 equiv.), and freshly activated molecular sieves (4Å, 300 mg) in CH_2Cl_2 (8.0 mL) was stirred under argon for 1 h. The solution was cooled to – 78 °C and NIS (1.1 equiv.) and TfOH (10 mol%) were added. The reaction was slowly allowed to reach 0 °C. Upon completion, the reaction was quenched by adding Et_3N. The solid was filtered off and the filtrate was washed with 1 M HCl, sat. $NaHCO_3$ solution, 10% $Na_2S_2O_3$ and brine. The organic layer was separated, dried with anhydrous Na_2SO_4, and concentrated *in vacuo*. The residue was purified by flash column chromatography on silica gel to afford the corresponding glycoside with 52% yield.

4.10 Analytical data for various deprotected uronic acids

4.10.1 *n*-Hexyl-2, 3, 4-tri-*O*-benzyl-D-glucopyranosiduronic acid (5a)

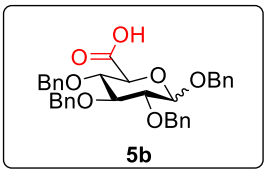


5a

White foam (123 mg, 90%); R_f value =0.5 in 50% EtOAc/ Hexane. IR:ν_{max} (neat) 3105, 1716, 1132 cm^{-1}; β:α isomer (>20:1);$[\alpha]_D^{24}$= -6.4 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 7.38–7.25 (m, 16H), 4.94 (dd, *J* = 17.6, 11.0 Hz, 2H), 4.81 (d, *J* = 10.2 Hz, 2H), 4.75 (d, *J* = 11.0 Hz, 1H), 4.67 (d, *J* = 10.7 Hz, 1H), 4.54 (d, *J* = 7.6 Hz, 1H), 4.01–3.96 (m, 2H), 3.85 (t, *J* = 9.1 Hz, 1H), 3.72 (t, *J* = 8.8 Hz, 1H), 3.59–3.52 (m, 2H), 1.70–1.64 (m, 2H), 1.43–1.30 (m, 8H), 0.92–0.89 (m, 3H).^{13}C NMR (125

MHz, $CDCl_3$) δ 172.9, 138.2, 138.1, 137.4, 128.4, 128.4, 128.1, 128.1, 127.9, 127.8, 127.7, 127.7, 103.7, 83.5, 81.5, 78.8, 75.6, 75.0, 74.7, 74.0, 70.5, 31.6, 29.6, 25.7, 22.5, 14.0. HRMS: Calc. for $C_{33}H_{41}O_7[M+H]^+$: 549.2852, Obser. 549.2849

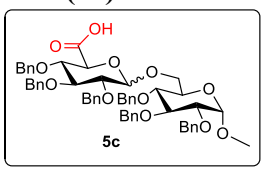
4.10.2 (Phenylmethyl)-2,3,4-tri-*O*-benzyl-D-glucopyranosiduronic acid (5b)



5b

Viscous liquid. (130 mg, 94%); R_f value =0.6 in 50% EtOAc/ Hexane. IR: ν_{max} (neat) 3215, 1705, 1145 cm^{-1}. β:α isomer (>20:1);$[\alpha]_D^{24}$= -19.6 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 7.37-7.24 (m, 21H), 4.98 (d, J = 12.1 Hz, 1H), 4.90 (m, 2H), 4.79 (t, J = 10.4 Hz, 2H), 4.68 (m, 4H), 4.00 (d, J = 9.3 Hz, 1H), 3.88–3.84 (m, 1H), 3.70 (t, J = 8.7 Hz, 1H), 3.59 (t, J = 7.7 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.7, 138.2, 138.0, 137.4, 136.9, 128.5, 128.4, 128.4, 128.3, 128.1, 128.0, 128.0, 127.9, 127.8, 127.7, 127.7, 102.5, 83.5, 81.6, 78.7, 75.6, 75.0, 74.8, 74.0, 71.5. HRMS: Calc. for $C_{34}H_{35}O_7[M+H]^+$:555.2383, Obser. 555.2387

4.10.3 (2S,4S,5S,6R)-3,4,5-*tris*(benzyloxy)-6-(((2R,4S,5S,6S)-3,4,5-*tris*(benzyloxy) -6-methoxytetra-hydro-2H-pyran-2-yl)methoxy)tetrahydro-2H-pyran-2-carboxylic acid (5c)

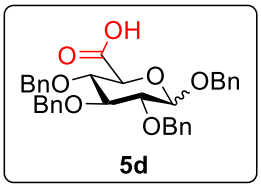


5c

White solid (198 mg, 87%); M.P: 93-95 ^oC; R_f value =0.5 in 60% EtOAc/ Hexane. IR: ν_{max} (neat) 3345, 1701, 1065 cm^{-1}. β:α isomer (3:2); $[\alpha]_D^{24}$= +34.5 [c 0.1, $CHCl_3$]; ^1H NMR (500 MHz, $CDCl_3$) δ 7.38–7.19 (m, 31H), 5.01–4.50 (m, 14H), 4.10–3.44 (m,

10H), 3.36 (d, *J* = 20.3 Hz, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ172.0, 170.4, 138.8, 138.7, 138.3, 138.2, 138.2, 138.1, 138.1, 138.0, 138.0, 137.5, 137.5, 128.4, 128.4, 128.3, 128.3, 128.3, 128.1, 128.1, 128.0, 128.0, 127.9, 127.9, 127.8, 127.8, 127.8, 127.7, 127.7, 127.6, 127.5, 103.5, 98.1, 98.0, 97.5, 96.1, 83.1, 82.0, 81.9, 81.2, 80.9, 80.1, 79.9, 79.3, 79.0, 78.7, 77.8, 77.7, 75.7, 75.7, 75.6, 75.3, 75.1, 75.0, 74.9, 74.8, 74.6, 73.9, 73.3, 72.6, 70.3, 69.9, 69.4, 69.0, 66.7, 55.3, 55.2.HRMS: Calc. for $C_{55}H_{59}O_{12}[M+H]^+$:911.4007, Obser. 911.4012

4.10.4 (Phenylmethyl)-2, 3, 4-tri-*O*-benzyl-D-glucopyranosiduronic acid (5d)



5d

Viscous liquid. (116 mg, 84%); R_f value = 0.6 in 50% EtOAc/ Hexane. IR: ν_{max} (neat) 3217, 1708, 1085 cm^{-1}.β:α isomer (~3:1);$[\alpha]_D^{24}$= +8.8 [c 0.1, $CHCl_3$];^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43–7.26 (m, 20H), 5.00 (dd, *J* = 17.1, 11.4 Hz, 1H), 4.93–4.85 (m, 2H), 4.83–4.66 (m, 5H), 4.03 (d, *J* = 9.1 Hz, 1H), 3.87 (t, *J* = 8.9 Hz, 1H), 3.71 (t, *J* = 8.6 Hz, 1H), 3.61–3.58 (m, 1H).^{13}C NMR (125 MHz, $CDCl_3$) δ 174.0, 173.0, 138.5, 138.2, 138.0, 137.8, 137.5, 136.96, 136.5, 128.5, 128.5, 128.5, 128.4, 128.4, 128.4, 128.2, 128.1, 128.1, 128.0, 128.0, 128.0, 127.9, 127.9, 127.8, 127.7, 127.7, 102.6, 95.9, 83.6, 81.6, 81.4, 79.3, 79.1, 78.7, 75.9, 75.6, 75.3, 75.0, 74.8, 74.0, 73.2, 71.5, 69.9, 69.7. HRMS: Calc. for $C_{34}H_{35}O_7$ $[M+H]^+$:555.2383, Obser. 555.2381

4.11 Spectral data of few products

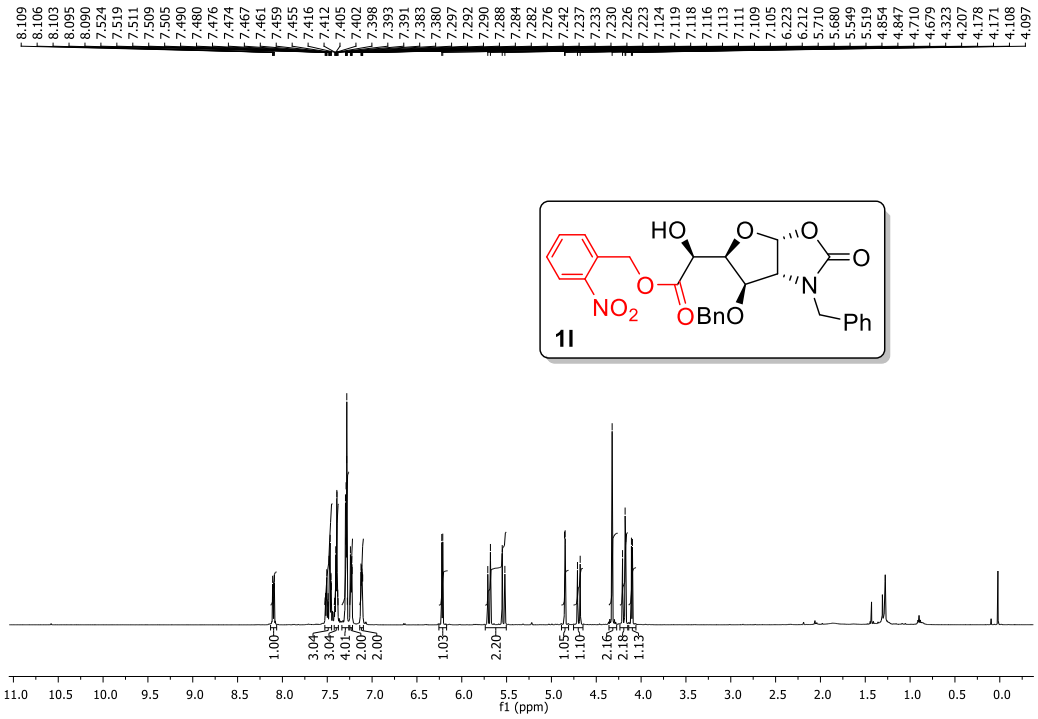


Figure 4.3 ^{1}H-NMR spectrum of compound **1l** in $CDCl_3$

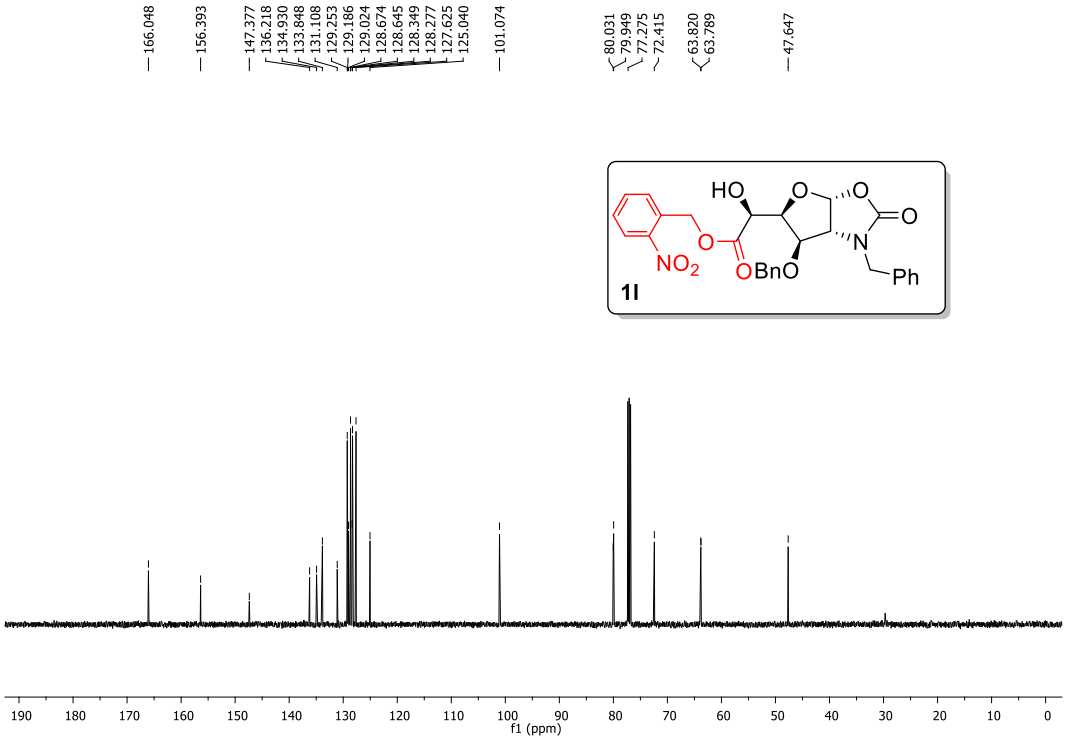


Figure 4.4 ^{13}C-NMR spectrum of compound **1l** in $CDCl_3$

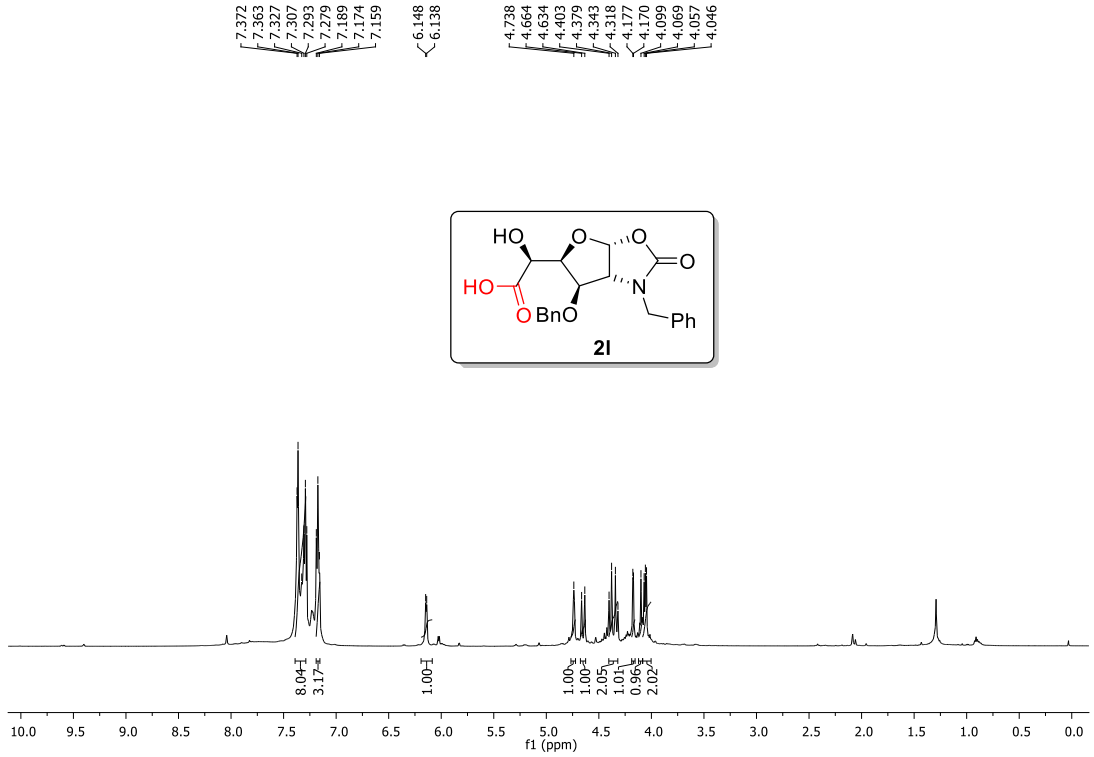


Figure 4.5 ^{1}H-NMR spectrum of compound **2l** in $CDCl_3$

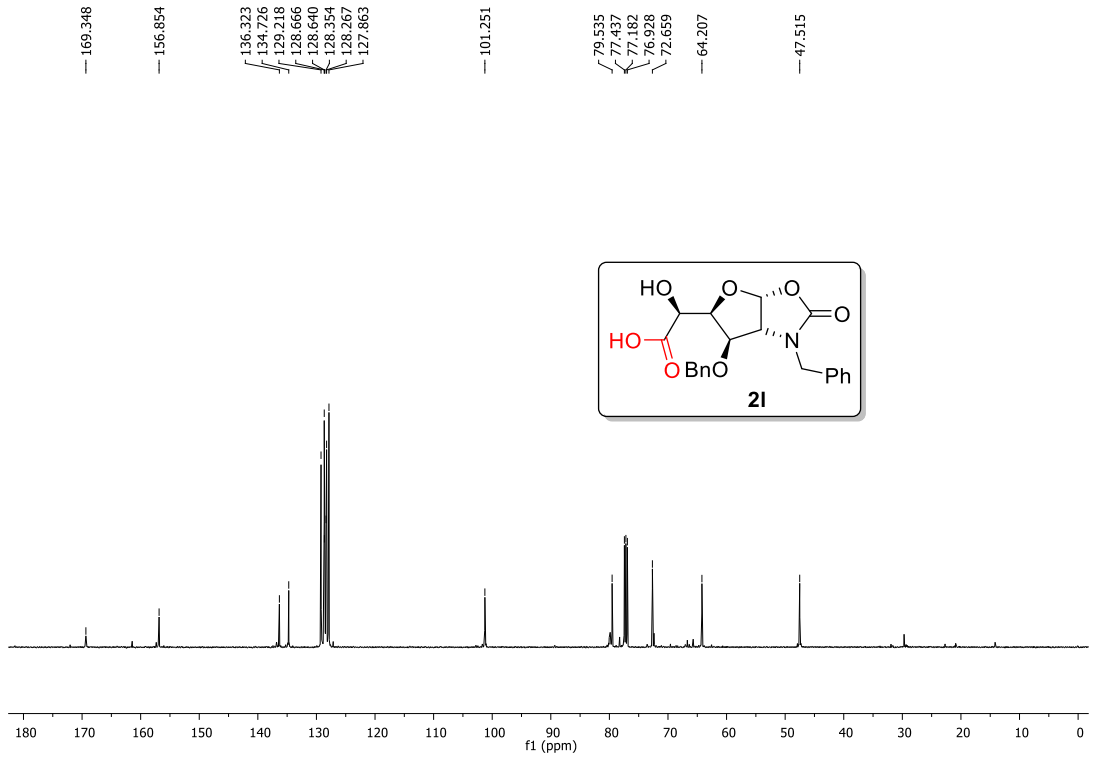


Figure 4.6 ^{13}C-NMR spectrum of compound **2l** in $CDCl_3$

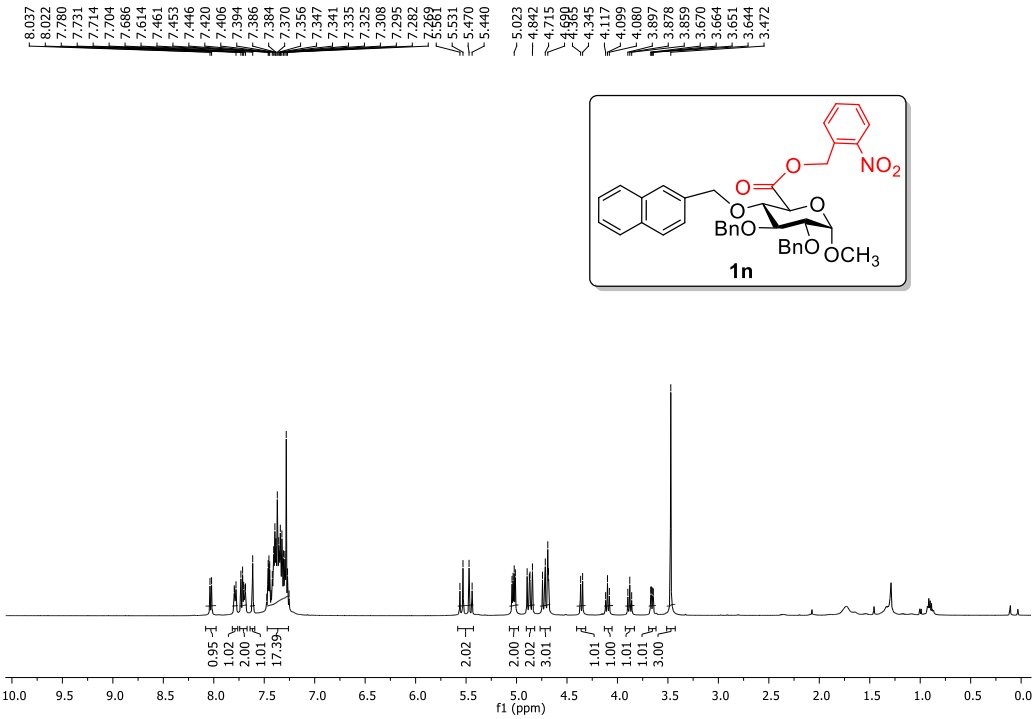


Figure 4.7 ^{1}H-NMR spectrum of compound **1n** in $CDCl_3$

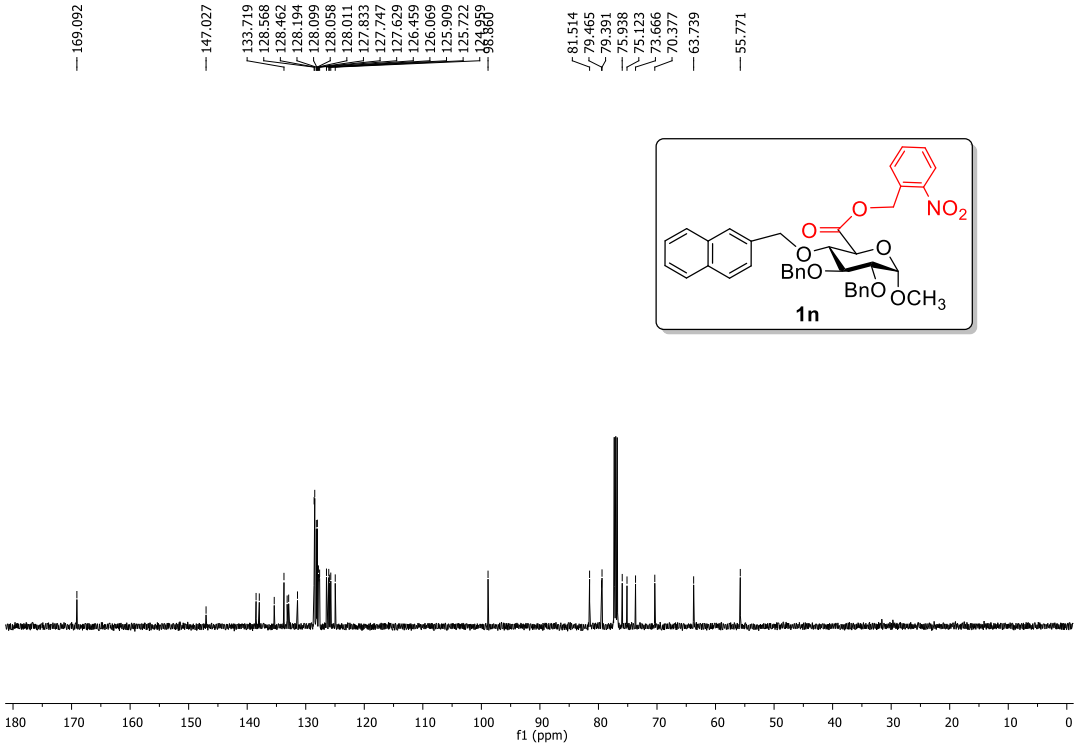


Figure 4.8 ^{13}C-NMR spectrum of compound **1n** in $CDCl_3$

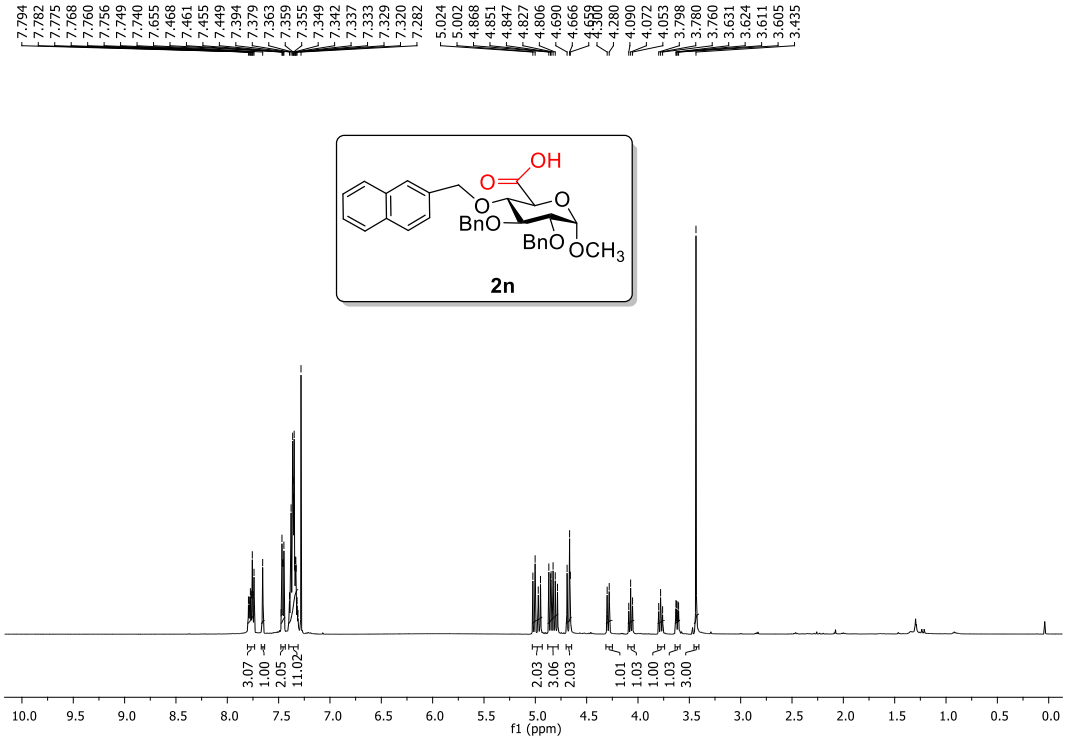


Figure 4.9 ^{1}H-NMR spectrum of compound **2n** in $CDCl_3$

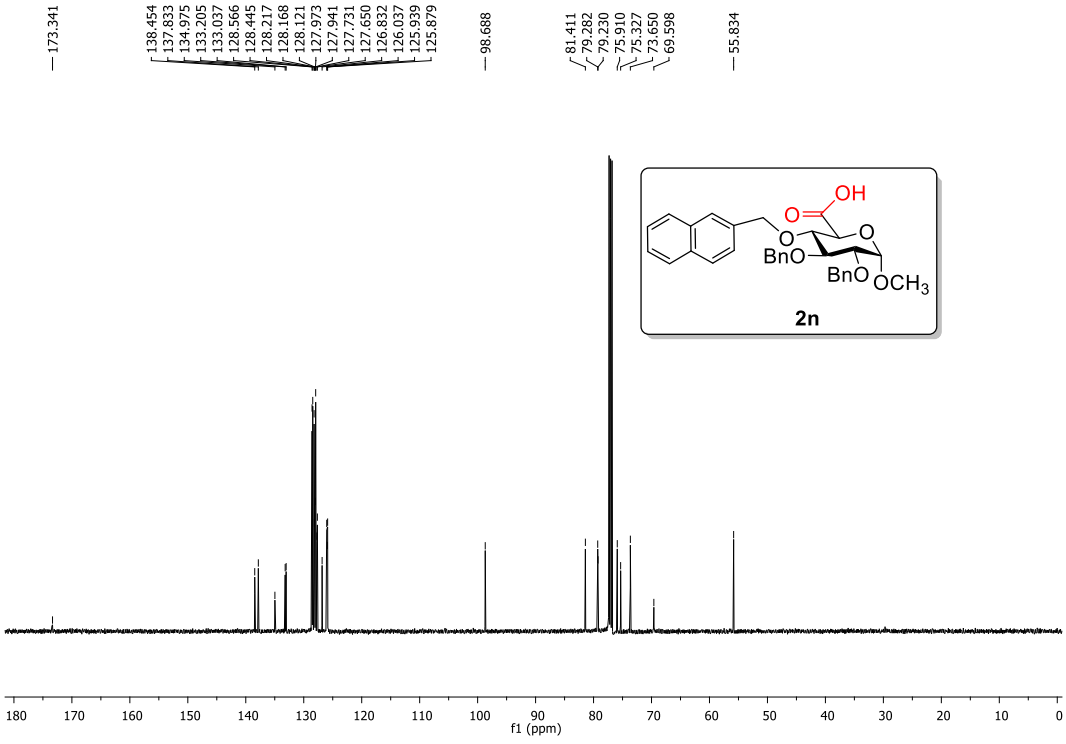


Figure 4.10 ^{13}C-NMR spectrum of compound **2n** in $CDCl_3$

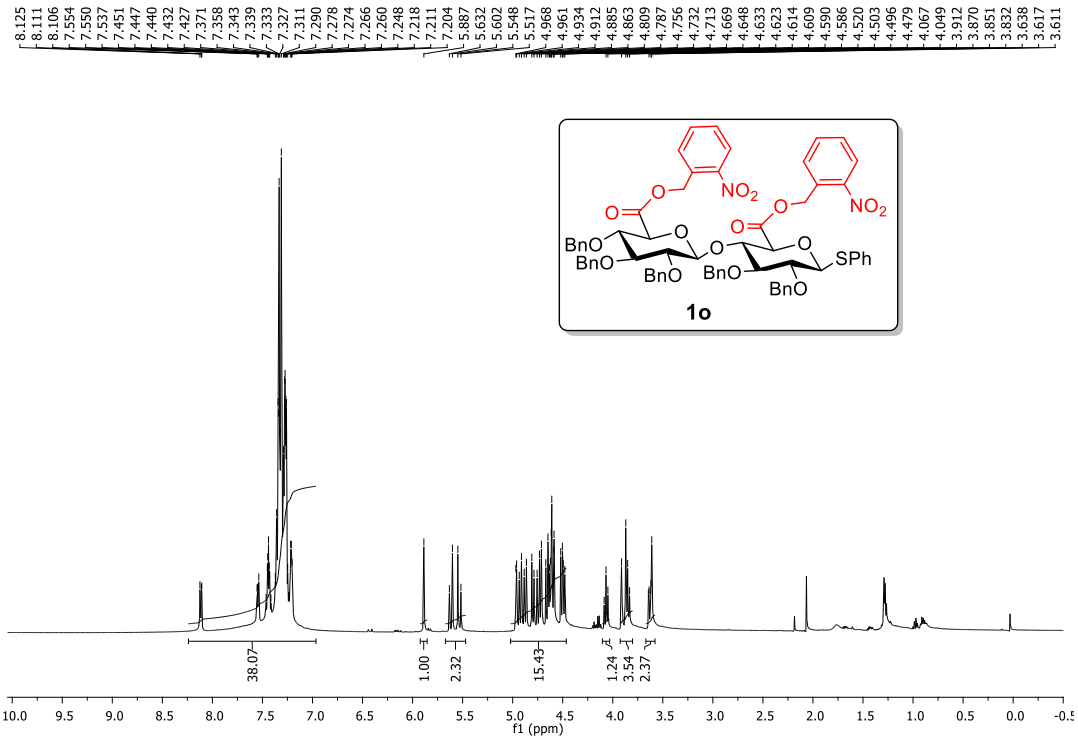


Figure 4.11 ^{1}H-NMR spectrum of compound **1o** in $CDCl_3$

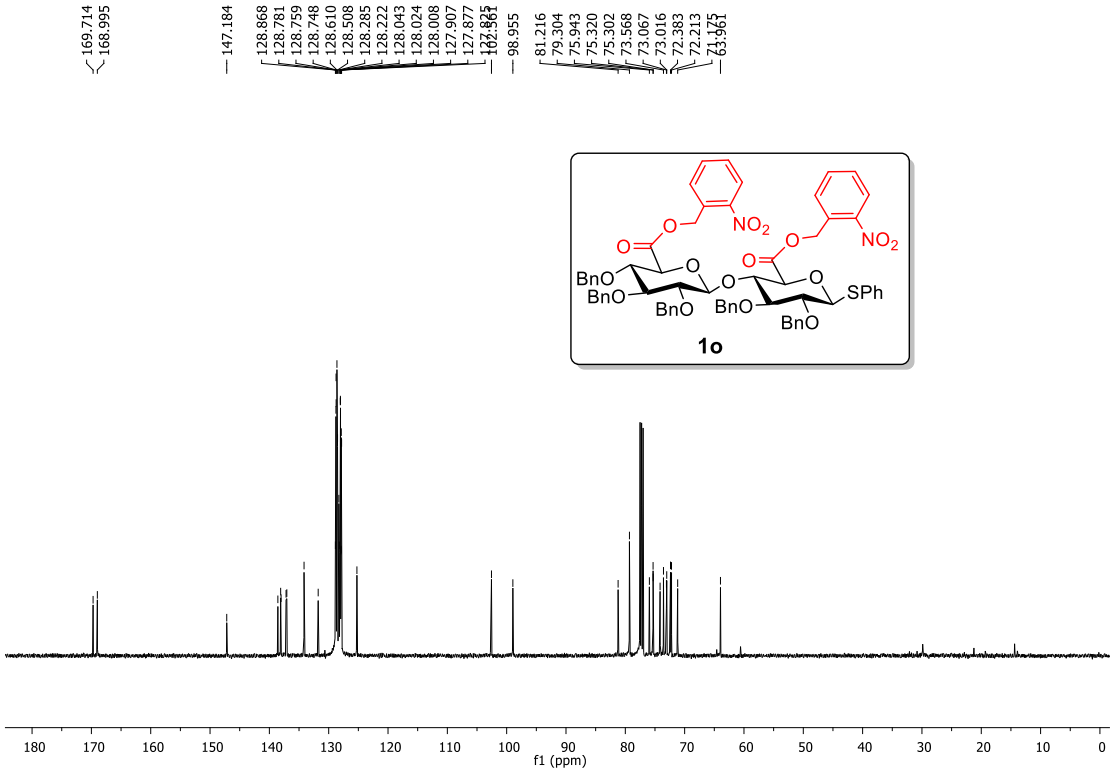


Figure 4.12 ^{13}C-NMR spectrum of compound **1o** in $CDCl_3$

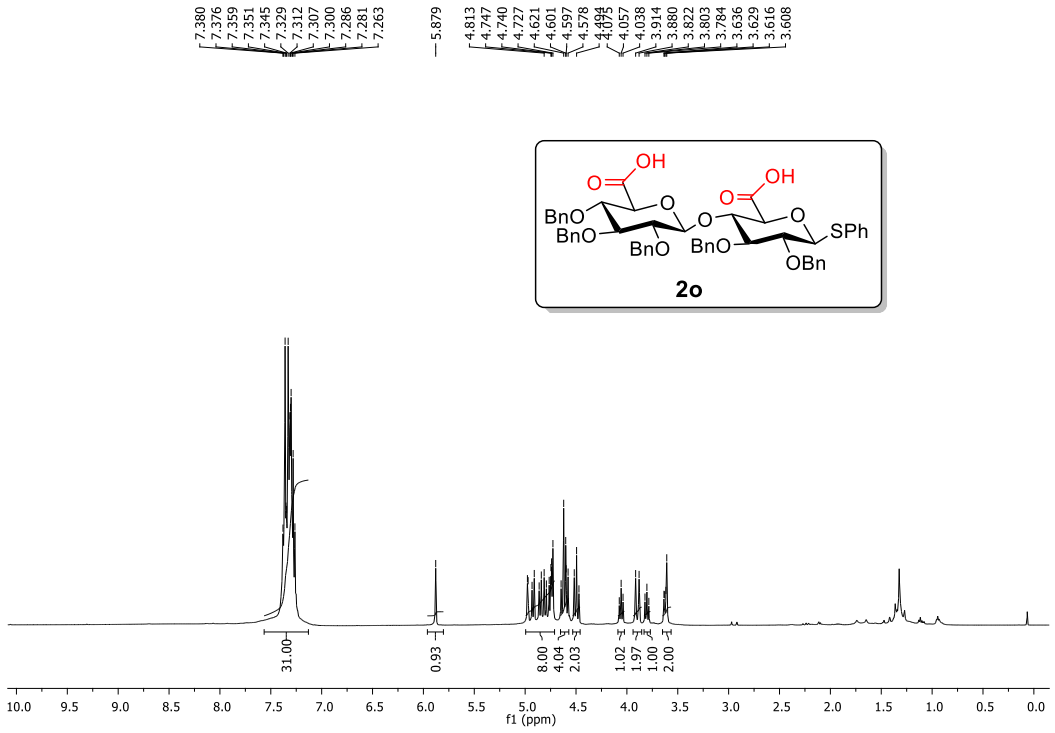


Figure 4.13 ^{1}H-NMR spectrum of compound **2o** in $CDCl_3$

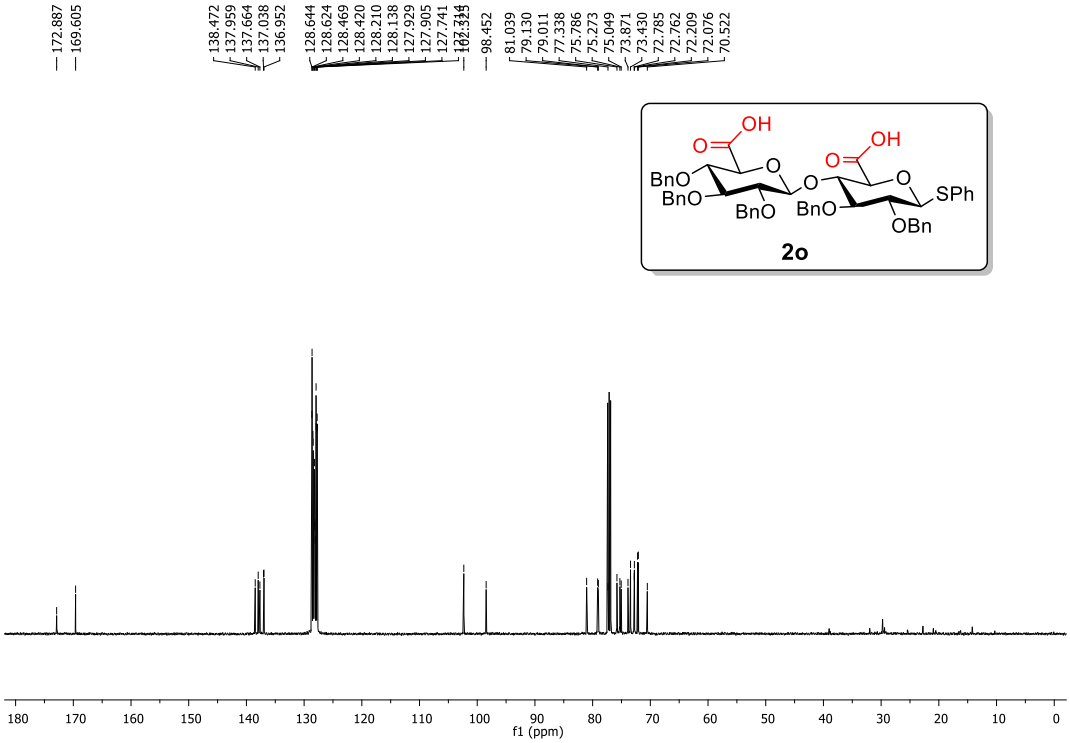


Figure 4.14 ^{13}C-NMR spectrum of compound **2o** in $CDCl_3$

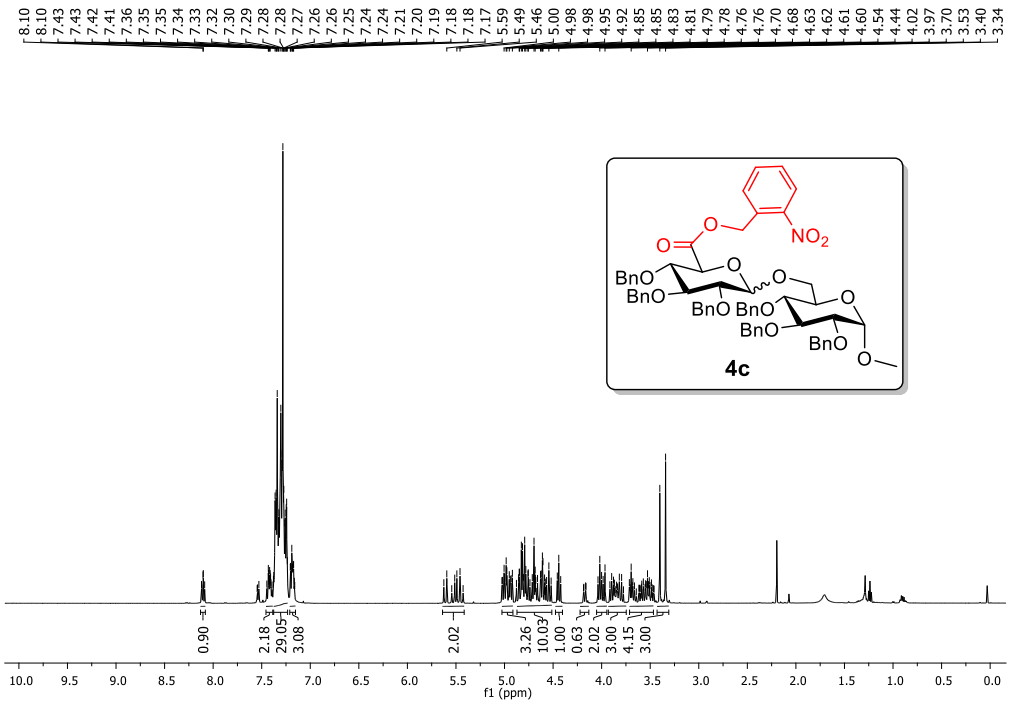


Figure 4.15 ^{1}H-NMR spectrum of compound **4c** in $CDCl_3$

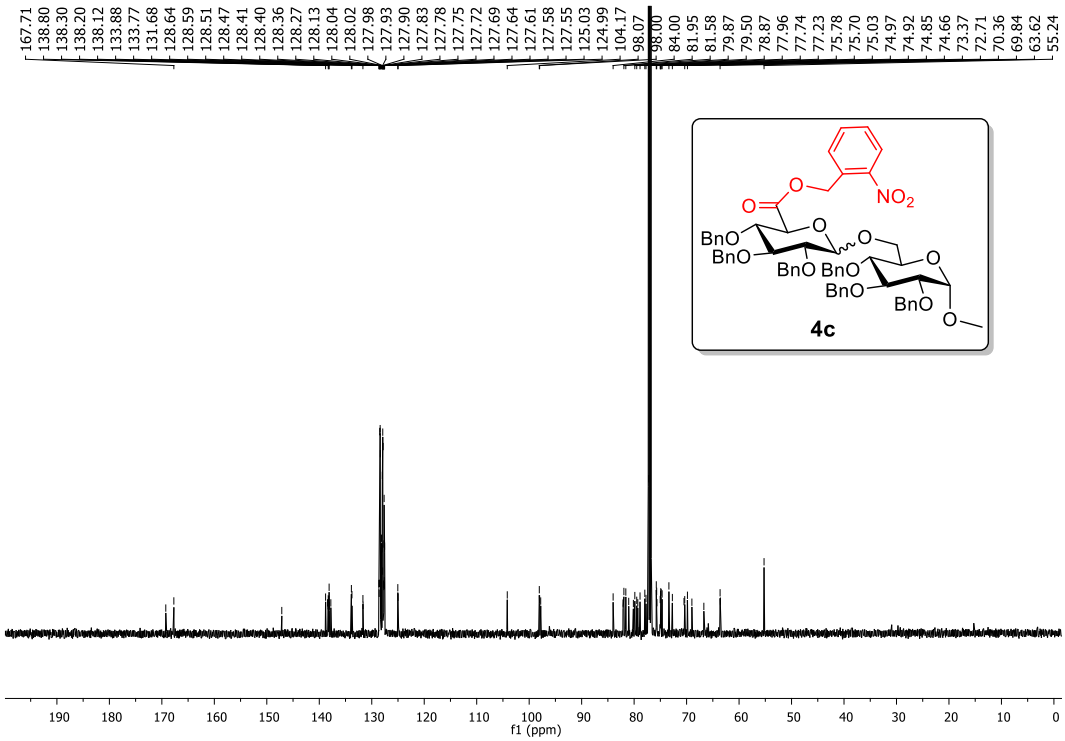


Figure 4.16 ^{13}C-NMR spectrum of compound **4c** in $CDCl_3$

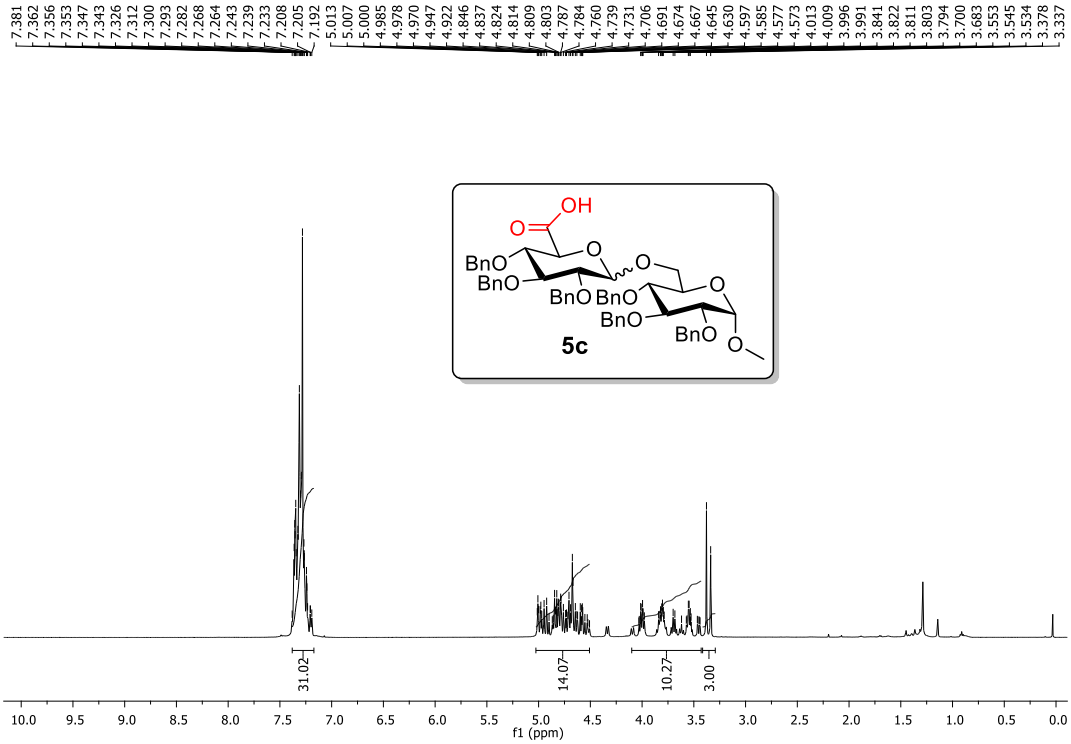


Figure 4.17 ^{1}H-NMR spectrum of compound **5c** in $CDCl_3$

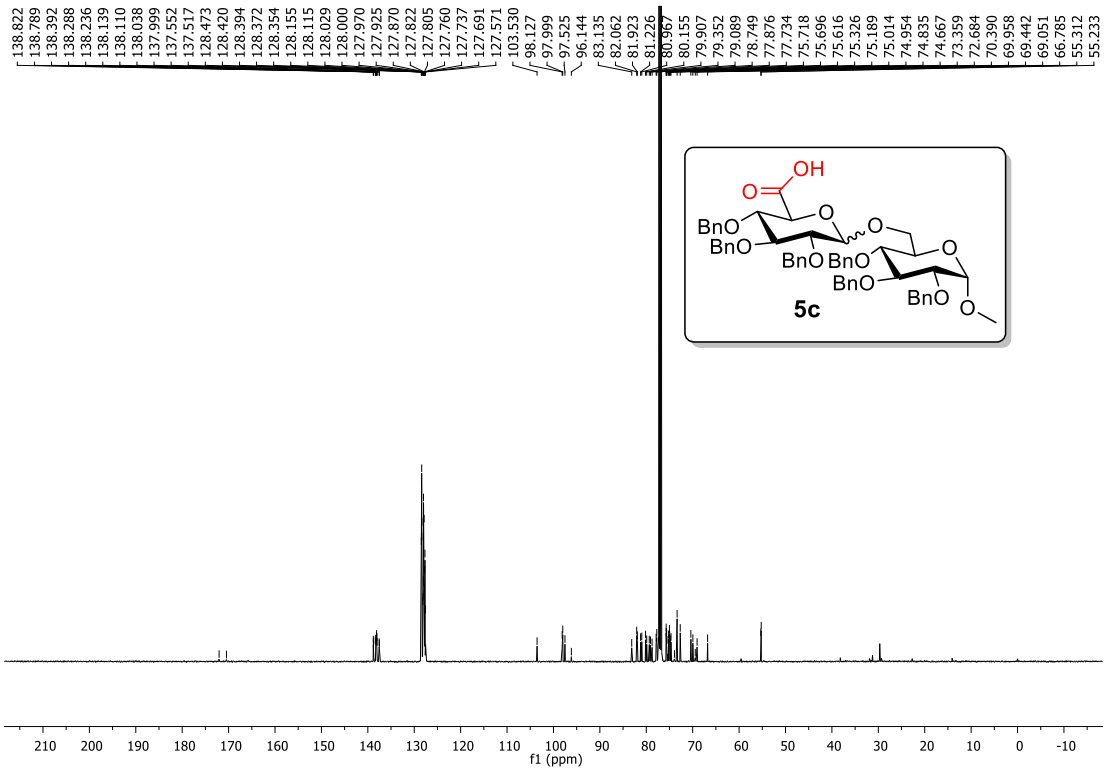


Figure 4.18 ^{13}C-NMR spectrum of compound **5c** in $CDCl_3$

4.12 References

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[10] We have observed only less than 5% of decomposition of PPG protected uronic acid **1a** after 48 hours under indoor lightening (5W white LED was used). To check the effect of sunlight, an experiment was performed in open sunlight during the month of September (under North-East Indian climatic conditions, room temperature (33-35 ^{o}C). The PPG protected uronic acid **1a** (100 mg) was dissolved in methanol (2 mL) and was kept in sunlight for the period of 1 hour. Only less than 5% of decomposition of **1a** was observed.

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