Synthesis of 6-Deoxyheptose Derivatives via Cyclic Sulfates and Oxetanes

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Abstract: Two approaches for the chain elongation and synthesis of 6-deoxyheptose derivatives are described. The first one is based on the regioselective ring opening of 4,6-cyclic sulfate glycopyranoside derivatives at carbon 6 by cyanide ion. The second approach involves the ring expansion of 5,6-anhydro to 5,7-anhydro sugars and subsequent opening of the resulting oxetane derivative using acetate ion as nucleophile.

Key words: chain elongation, 6-deoxyheptoses, cyclic sulfate, oxetanes, oxiranes

Naturally occurring 6-deoxyheptoses have been found as constituents of bacterial polysaccharides[1] although little is known about their biosynthesis and biological role. Most of the reported synthetic approaches are based on chain extension at the C-6 position of hexoses, e.g. via a nitrile, a Wittig reaction, dithioacetals and organometallic reagents, among others.[1] Cyclic sulfates of monosaccharides[2,3] or 5,6-anhydroaldose[4–6] derivatives have been used in some of those approaches as precursors of 6-deoxyheptoses. In this paper we wish to report further on the applications of these two classes of compounds in the synthesis of 6-deoxyheptose derivatives.

The use of cyclic sulfates as an active form of diols towards nucleophilic attack provides an efficient and versatile method in synthesis.[7–9] We have investigated the reactivity of cyclic sulfates of sugars and discovered some interesting applications in the synthesis of episulfide and olefin derivatives, thiosugars[10,11] and, as well, thio-linked disaccharides.[12] On the other hand, it is known that oxiranes undergo ring expansion when treated with dimethylsulfoxonium methylide affording oxetanes.[13,14] Since oxetanes are latent 1,3-diols, we can envisage a new method for the chain elongation at C-6 of hexoses, and hence, for the synthesis of 6-deoxyheptoses, from 5,6-anhydrohexofuranose derivatives.

Cyclic sulfates of sugars with D-*gluco*, D-*manno* and D-*galacto* configuration **1–6** were prepared in good to high yields (Table 1) from the corresponding diols following a synthetic route described earlier for **3** and **6**[11,12] which was based on the procedure by Gao and Sharpless.[15] The reaction of compounds **1–6** with lithium or sodium cyanide was performed in DMF at room temperature for 4–40 hours giving rise to the lithium or sodium sulfate derivatives **7–12** in good yields (Table 2, entries 1–7). As expected, the nucleophilic ring opening of the 4,6-cyclic sulfates **1–5** occurred regioselectively at the less sterically hindered 6-position and the reaction conditions were compatible with ester protection of the hydroxyl groups at C-2,3. However, the reaction of the less reactive 3,4-cyclic sulfate **6** with lithium or sodium cyanide failed to give the corresponding nitrile derivative and instead, the 2,3-anhy-

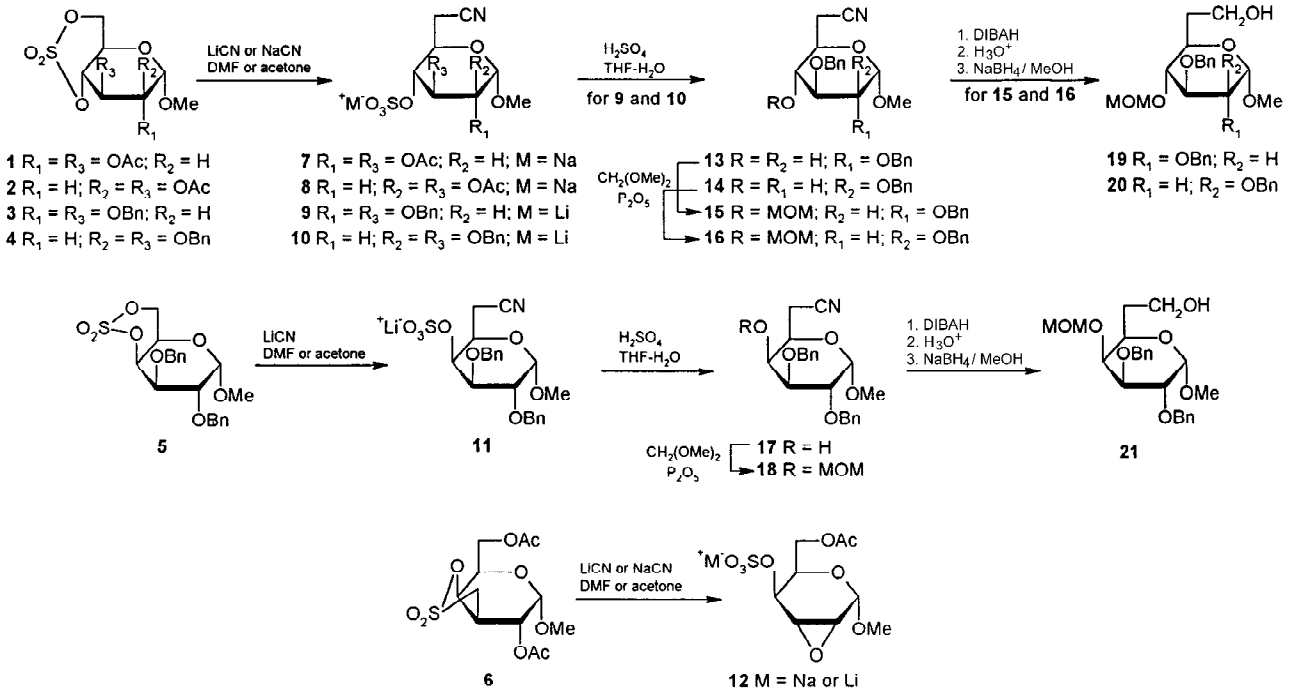

Table 1. Cyclic Sulfates **1**, **2**, **4** and **5** Prepared

Product[a]	Yield (%)	mp (°C)	$[a]_D^{25}$ (*c*, MeOH)	IR (KBr) ν (cm^{-1})	^1H NMR (300 MHz, $CDCl_3$/TMS) δ, *J* (Hz)	^{13}C NMR (75 MHz, $CDCl_3$/TMS) δ
1	92	155–156	+ 110 (1)	1749, 1205	2.09, 2.10 (2s, 6 H, 2 CH_3CO), 3.45 (s, 3 H, CH_3O), 4.27 (ddd, 1 H, *J* = 5.3, 10.5, 10.5, H–5), 4.55 (dd, 1 H, *J* = 5.3, 10.5, H–6), 4.62 (dd, 1 H, *J* = 10.5, H–4), 4.65 (t, 1 H, *J* = 10.5, H–6'), 4.83 (dd, 1 H, *J* = 3.6, 9.9, H–2), 5.03 (d, 1 H, *J* = 3.6, H–1), 5.61 (t, 1 H, *J* = 9.9, H–3)	20.6 (2 *C*H_3CO), 56.2 (CH_3O), 60.6, 67.1, 70.8 (C–2, 3, 5), 72.1 (C–6), 81.4 (C–4), 97.7 (C–1), 169.3, 170.1 (C=O)
2	90	135–140	+ 32 (1)	1749, 1245, 1208	2.06, 2.16 (2s, 6 H, 2 CH_3CO), 3.44 (s, 3 H, CH_3O), 4.24 (ddd, 1 H, *J* = 5.0, 10.5, 10.2, H–5), 4.55 (dd, 1 H, *J* = 5.0, 10.6, H–6), 4.71 (d, 1 H, *J* = 1.6, H–1), 4.72 (dd, 1 H, *J* = 10.7, H–6'), 4.94 (t, 1 H, *J* = 10.2, H–4), 5.43 (dd, 1 H, *J* = 1.6, 3.5, H–2), 5.43 (dd, 1 H, *J* = 3.6, 10.4, H–3)	20.6, 20.7 (2 *C*H_3CO), 56.0 (CH_3O), 61.9, 66.8, 69.4 (C–2, 3, 5), 72.1 (C–6), 79.5 (C–4), 99.8 (C–1), 169.4, 170.5 (C=O)
4	85	102–103	+ 58 (1)	1727, 1636, 1412, 1202	3.33 (s, 3 H, CH_3O), 3.81 (dd, 1 H, *J* = 2.0, 3.2, H–2), 3.94 (dd, 1 H, *J* = 3.2, 10.0, H–3), 4.05 (dt, 1 H, *J* = 4.9, 10.5, H–5), 4.48 (dd, 1 H, *J* = 4.9, 10.5, H–6), 4.58 (d, 1 H, *J* = 12.0, PhC*H*), 4.64 (d, 1 H, *J* = 12.0, PhC*H*), 4.67 (d, 1 H, *J* = 2.0, H–1), 4.69 (t, 1 H, *J* = 10.5, H–6'), 4.73 (d, 1 H, *J* = 12.0, PhC*H*'), 4.79 (d, 1 H, *J* = 12.0, PhC*H*'), 5.13 (t, 1 H, *J* = 10.0, H–4), 7.30–7.40 (m, 10 H, 2 C_6H_5)	55.5 (CH_3O), 62.1 (C–5), 72.2 (C–6), 73.2, 73.9 (2 Ph*C*), 75.3, 75.6 (C–2, 3), 83.1 (C–4), 100.6 (C–1), 127.6–137.5 (2 C_6H_5)
5	54	148–152	+ 68 (0.3)	1728, 1630, 1397, 1196	3.39 (s, 3 H, CH_3O), 3.89, 4.02 (2 dd, 2 H, *J* = 3.4, 10.0, H–2, 3), 4.53 (dd, 1 H, *J* = 1.5, 12.1, H–6), 4.66 (d, 1 H, *J* = 12.1, PhC*H*), 4.67–4.69 (m, 2 H, H–4, 5), 4.73 (d, 1 H, *J* = 12.0, PhC*H*), 4.80 (d, 1 H, *J* = 12.0, PhC*H*'), 4.81 (dd, 1 H, *J* = 1.5, 12.1, H–6'), 4.89 (d, 1 H, *J* = 12.1, PhC*H*'), 5.10 (d, 1 H, *J* = 3.4, H–1), 7.29–7.35 (m, 10 H, 2 C_6H_5)	56.1 (CH_3O), 60.0 (C–5), 72.7 (C–6), 73.6, 74.6 (C–2, 3), 74.2, 74.4 (Ph*C*), 82.0 (C–4), 99.2 (C–1), 127.7–138.0 (2 C_6H_5)

[a] Satisfactory microanalyses obtained: C ± 0.47, H ± 0.25.

dro salt **12** was obtained. Presumably, in these conditions the reaction proceeded by initial cyanolysis of the acetyl group at the *O*-2 and subsequent ring opening of the cyclic sulfate by internal nucleophilic attack of the resulting alkoxide at carbon 3.

In order to synthesize 6-deoxyheptose derivatives we subjected the 2,3-di-*O*-benzyl sulfates **9–11** to acidic hydrolysis obtaining the methyl 2,3-di-*O*-benzyl-6-deoxy-α-D-heptopyranosyluronononitriles **13**, **14, 17**, respectively, in 78–89.5% yields (Table 2, entries 8–10). It is noteworthy that, analogous to epoxides,[8,11] the opening of the cyclic sulfate ring followed by hydrolysis of the sulfate salt gave compounds having a free hydroxy group at C-4. This hydroxy group may serve as a glycosyl acceptor, may allow an inversion of the configuration[16] or may be orthogonally protected. At this stage, having obtained a nitrile group on the carbon 6, conversion of the nitrile function into a hydroxymethyl group can be undertaken following the procedure reported by Aspinall *et al.*,[16] namely, diisobutylaluminium hydride (DIBAH) reduction, hydrolysis of the resulting imine and further reduction with sodium borohydride. When compound **13** was treated with an excess of DIBAH no change was observed according to TLC. Then, the hydroxy group at C-4 was protected as its methoxymethyl ether. Thus, reaction of **13**, **14** and **17** with dimethoxymethane/P_2O_5 in dichloromethane afforded the 4-*O*-methoxymethyl derivatives **15, 16** and **18** in good yields after chromatographic purification (Table 2, entries 11–13). For the two step reduction of the 6-*C*-cyano derivatives, compounds **15, 16** and **18** were treated with DIBAH, followed by acid hydrolysis and subsequent treatment with sodium borohydride yielding the expected 6-deoxyheptopyranoside derivatives **19–21** (Table 3). Spectroscopic data of compounds **7–21** are given in Table 4.

To develop the second approach, we selected the 5,6-anhydro-D-*gluco* (**25a**), D-*manno* (**25b**), L-*ido* (**26a**), and L-*gulo*-furanose (**26b**) derivatives as starting materials. Compounds **25a**,**b** were synthesized from 3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-glucofuranoside (**22a**) and methyl 2,3-*O*-isopropylidene-α-D-mannofuranoside (**22b**), respectively. Thus, reaction of furanoside derivatives **22a**,**b**[17,18] with 2-naphthalenesulfonyl chloride generated **23a** (62%), and **23b + 24b** (47 and 15%), respectively. The 6-*O*-(2-naphthalenesulfonyl)furanosides **23a**,**b** could be converted to the epoxides derivatives **25a**,**b** by treatment with sodium methoxide in methanol. The products **25a**,**b** were isolated in 67 and 73% yields after column

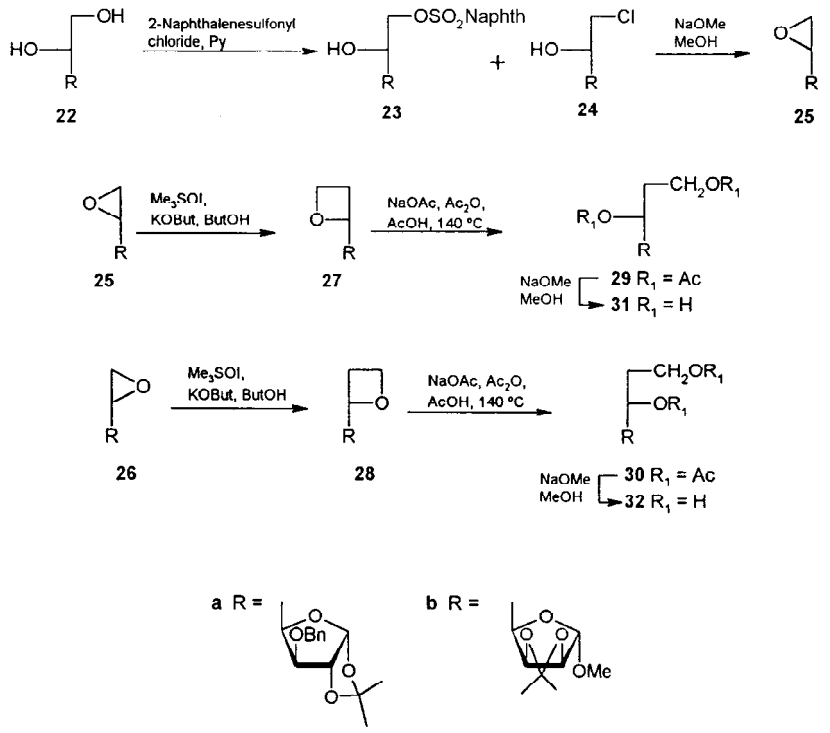

Table 2. Preparation of Compounds **7–18**

Entry	Substrate (mmol)	Reagent	Solvent	Time (h)	Solvent for Chromatography	Product	Yield (%)	mp (°C)	$[\alpha]_D^{25}$ (*c*, solvent)
1	**1** (0.59)	NaCN (1.5 equiv)	DMF	4	MeOH/$CHCl_3$ (1:6)	**7**	95	166–168	+ 90 (1, MeOH)
2	**2** (0.59)	NaCN (1.5 equiv)	DMF	4	MeOH/$CHCl_3$ (1:6)	**8**	79	161–163	+ 38 (1, MeOH)
3	**3** (1.62)	LiCN[a] (2.0 equiv)	acetone	26	MeOH/$CHCl_3$ (1:5)	**9**	98	129 (dec.)	+ 79 (1, MeOH)
4	**4** (0.47)	LiCN[a] (5.1 equiv)	acetone	40	MeOH/$CHCl_3$ (1:5)	**10**	94	133 (dec.)	+ 55 (0.5, MeOH)
5	**5** (0.32)	LiCN[a] (3.2 equiv)	acetone	45.5	MeOH/$CHCl_3$ (1:5)	**11**	93	126 (dec.)	+ 112 (0.25, MeOH)
6	**6** (0.50)	NaCN (2.5 equiv)	DMF	24	MeOH/$CHCl_3$ (1:5)	**12**	78	syrup	+ 32 (1, MeOH)
7	**6** (1.00)	LiCN[a] (1.1 equiv)	DMF	20	MeOH/$CHCl_3$ (1:5)	**12**	99	syrup	+ 32 (1, MeOH)
8	**9** (1.17)	H_2SO_4 (100 µL)	THF/H_2O (30:0.7 mL)	1.25	Et_2O/hexane (2:1)	**13**	89	111–112	+ 118 (0.25, MeOH)
9	**10** (0.44)	H_2SO_4 (40 µL)	THF/H_2O (15:0.2 mL)	3.5[b]	Et_2O/hexane (7:3)	**14**	84	100–101	– 8 (0.25, $CHCl_3$)
10	**11** (0.30)	H_2SO_4 (25 µL)	THF/H_2O (20:0.1 mL)	0.75	Et_2O/hexane (7:3)	**17**	78	syrup	+ 52 (0.75, $CHCl_3$)
11	**13** (1.74)	$(MeO)_2CH_2$ (25 mL) P_2O_5 (3.8 g)	25 mL	2.3	Et_2O/hexane (2:3)	**15**	87	67–69	+ 96 (0.25, $CHCl_3$)
12	**14** (3.57)	$(MeO)_2CH_2$ (50 mL) P_2O_5 (8.2 g)	50 mL	1.5	Et_2O/hexane (1:3)	**16**	86	syrup	+ 142 (0.25, $CHCl_3$)
13	**17** (1.42)	$(MeO)_2CH_2$ (40 mL) P_2O_5 (5.7 g)	40 mL	1.5	Et_2O/hexane (2:3)	**18**	56	syrup	+ 46 (0.25, $CHCl_3$)

[a] 0.5 M solution of LiCN in DMF.
[b] The reaction is complete upon heating at 40 °C.

chromatography, respectively. Similar treatment using the 6-chloro-6-deoxy derivative **24b** gave the corresponding 5,6-anhydro compound **25b** in 72% yield (Table 5, entries 1–5). The remaining 5,6-anhydro derivatives **26a**,**b** were prepared as described.[17,18]

Having the 5,6-anhydro furanosides in hand, we tested the key ring expansion reaction using dimethylsulfoxonium methylide as nucleophilic methylene transfer reagent. This reagent was prepared in situ from trimethysulfoxonium iodide and potassium *tert*-butoxide in *tert*-butyl alcohol. Thus, epoxides **25a**,**b** and **26a**,**b** were allowed to react in the presence of trimethysulfoxonium methylide for 6–20 hours at 50ºC, furnishing oxetanes **27a**,**b** and **28a**,**b** in 54–93% yields (see Table 5, entries 6–9). The reactions proceeded with excellent regioselectivity, wherein the methylene insertion into the bond between the oxirane oxygen and the primary carbon 6 took place.

Table 3. Reduction of Compounds **15**, **16** and **18**

Substrate (mmol)	DIBAH (mL)	Toluene (mL)	Time (h)	$NaBH_4$ (g)	MeOH (mL)	Time (h)	Solvent for Chromatography	Product	Yield (%)	mp (°C)	$[\alpha]_D^{25}$ (*c*, $CHCl_3$)
15 (0.12)	0.26[a]	7	1.5	0.03	5	1.5	Et_2O/hexane (4:1)	**19**	40	56	+ 101 (0.25)
16 (3.08)	10[b]	20	0.75	1.65	35	0.5	Et_2O/hexane (3:1)	**20**	59	syrup	+ 88 (0.45)
18 (0.21)	0.7[b]	5	0.95	0.11	12	1.65	Et_2O	**21**	25	syrup	+ 34 (0.20)

[a] 1 M in THF.
[b] 1 M in hexane.

Table 4. Spectroscopic Data for Compounds **7–21**

Product[a]	IR (KBr) ν (cm^{-1})	^1H NMR (300 MHz, solvent/TMS) δ, *J* (Hz)	^{13}C NMR (75 MHz, solvent/TMS) δ
7	2261, 1749	DMSO-d_6: 1.92, 2.00 (2s, 6 H, 2 CH_3CO), 2.81 (dd, 1 H, *J* = 8.2, 17.2, H–6), 3.06 (dd, 1 H, *J* = 3.4, 17.2, H–6'), 3.34 (s, 3 H, CH_3O), 3.71 (m, 1 H, H–5), 4.00 (t, 1 H, *J* = 9.6, H–4), 4.73 (dd, 1 H, *J* = 3.3, 10.7, H–2), 4.90 (d, 1 H, *J* = 3.3, H–1), 5.18 (t, 1 H, *J* = 10.1, H–3)	DMSO-d_6: 20.1 (C–6), 20.5, 20.8 (2 *C*H_3CO), 54.8 (CH_3O), 66.4, 69.2, 70.0, 74.5 (C–2, 3, 4, 5), 96.0 (C–1), 118.1 (CN), 169.5, 169.7 (2 C=O)
8	1748, 1255	DMSO-d_6: 1.92, 2.14 (2 s, 6 H, 2 CH_3CO), 2.83 (dd, 1 H, *J* = 5.3, 17.2, H–6), 3.09 (dd, 1 H, *J* = 3.4, 17.2, H–6'), 3.37 (s, 3 H, CH_3O), 3.73 (ddd, 1 H, *J* = 3.4, 5.3, 9.7, H–5), 4.18 (t, 1 H, *J* = 9.7, H–4), 4.74 (d, 1 H, *J* = 1.7, H–2), 4.97 (dd, 1 H, *J* = 3.6, 1.7, H–2), 5.07 (dd, 1 H, *J* = 9.6, 3.6, H–3)	DMSO-d_6: 20.4 (C–6), 20.6, 20.7 (2 *C*H_3CO), 54.6 (CH_3O), 67.3, 68.2, 69.3, 71.9 (C–2, 3, 4, 5), 97.5 (C–1), 118.1 (CN), 169.6 (2 C=O)
9	2254, 1654, 1260, 1025	DMSO-d_6: 2.88 (dd, 1 H, *J* = 7.5, 16.6, H–6), 3.19 (br d, 1 H, *J* = 16.6, H–6'), 3.32 (s, 3 H, CH_3O), 3.40 (dd, 1 H, *J* = 2.0, 9.7, H–2), 3.65–3.70 (m, 1 H, H–5), 3.65, 4.00 (2 t, 2 H, *J* = 9.7, H–3, 4), 4.56, 5.00 (2 d, 2 H, *J* = 10.9, PhCH_2), 4.82 (d, 1 H, *J* = 2.0, H–1), 4.62 (s, 2 H, PhCH_2), 7.24–7.39 (m, 10 H, 2 C_6H_5)	DMSO-d_6: 20.3 (C–6), 54.6 (CH_3O), 66.3 (C–5), 71.8, 73.8 (2 Ph*C*H_2), 77.7, 78.2, 79.0 (C–2, 3, 4), 97.0 (C–1), 118.4 (CN), 132.4–133.4 (2 C_6H_5)
10	2270, 1653, 1214, 1000	DMSO-d_6: 2.82 (dd, 1 H, *J* = 8.0, 17.2, H–6), 3.20 (dd, 1 H, *J* = 3.2, 17.2, H–6'), 3.23 (s, 3 H, CH_3O), 3.58–3.65 (m, 2 H, H–3,5), 3.70 (t, 1 H, *J* = 2.5, H–2), 4.32 (dd, 1 H, *J* = 8.5, 9.4, H–4), 4.56, 4.82 (2 d, 2 H, *J* = 12.1, PhCH_2), 4.63 (s, 2 H, PhCH_2), 4.75 (d, 1 H, *J* = 2.5, H–1), 7.23–7.29 (m, 10 H, 2 C_6H_5)	DMSO-d_6: 20.5 (C–6), 54.3 (CH_3O), 71.7, 71.8 (2 Ph*C*H_2), 67.8, 74.9, 75.9, 76.6 (C–2, 3, 4, 5), 98.4 (C–1), 118.5 (CN), 127.0–139.1 (2 C_6H_5)
11[b,c]	2259, 1652, 1256, 1036	DMSO-d_6: 2.81 (dd, 1 H, *J* = 3.9, 16.9, H–6), 2.88 (dd, 1 H, *J* = 11.0, 16.9, H–6'), 3.49 (s, 3 H, CH_3O), 3.63 (dd, 1 H, *J* = 3.5, 10.3, H–2), 3.75 (dd, 1 H, *J* = 3.0, 10.3, H–3), 3.95 (m, 1 H, H–5), 4.45, 4.58 (2 d, 2 H, *J* = 11.8, PhCH_2), 4.67, 4.87 (2 d, 2 H, *J* = 11.8, PhCH_2), 4.69 (d, 1 H, *J* = 3.0, H–4), 4.82 (d, 1 H, *J* = 3.5, H–1), 7.30 – 7.50 (m, 10 H, 2 C_6H_5)	DMSO-d_6: 20.2 (C–6), 55.6 (CH_3O), 65.9 (C–5), 69.8 (Ph*C*H_2), 71.6 (C–4), 72.6 (Ph*C*H_2), 74.8 (C–2), 75.6 (C–3), 97.7 (C–1), 118.9 (CN), 127.0–139.2 (2 C_6H_5)
12	1735, 1244[d]	DMSO-d_6: 1.98 (s, 3 H, CH_3CO), 3.28 (s, 3 H, CH_3O), 3.40 (dd, 1 H, *J* = 3.1, 3.7, H–2), 3.45 (dd, 1 H, *J* = 2.2, 3.8, H–3), 3.80 (ddd, 1 H, *J* = 2.0, 3.2, 8.2, H–5), 4.00 (dd, 1 H, *J* = 8.2, 10.0, H–6), 4.07 (dd, 1 H, *J* = 3.2, 12.0, H–6'), 4.32 (br t, 1 H, *J* = 2.0, H–4), 4.95 (d, 1 H, *J* = 3.1, H–1)	DMSO-d_6: 20.6 (*C*H_3CO), 50.2, 50.4 (C–2, 3), 54.2 (CH_3O), 64.2 (C–6), 65.1, 67.4 (C–4, 5), 93.9 (C–1), 170.1 (C=O)
13	3466, 2252, 1497, 1053[d]	$CDCl_3$: 2.10 (d, 1 H, *J* = 0.8, OH), 2.57 (dd, 1 H, *J* = 7.1, 16.8, H–6), 2.77 (dd, 1 H, *J* = 3.3, 16.8, H–6'), 3.35 (br t, 1 H, *J* = 9.2, H–4), 3.43 (s, 3 H, CH_3O), 3.56 (dd, 1 H, *J* = 3.6, 9.6, H–2), 3.74–3.80 (m, 2 H, H–3,5), 4.65 (d, 1 H, *J* = 3.6, H–1), 4.67, 4.72 (2 d, 2 H, *J* = 11.5, PhCH_2), 4.78, 5.05 (2 d, 2 H, *J* = 1.5, PhCH_2), 7.35–7.40 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 20.8 (C–6), 55.5 (CH_3O), 66.7 (C–5), 72.5 (C–4), 73.3, 75.4 (2 Ph*C*H_2), 79.7, 80.7 (C–2, 3), 98.2 (C–1), 117.1 (CN), 127.0–139.1 (2 C_6H_5)
14[b]	3474, 2259, 1454, 1049	$CDCl_3$: 2.39 (d, 1 H, *J* = 1.9, OH), 2.61 (dd, 1 H, *J* = 8.5, 16.8, H–6), 2.89 (dd, 1 H, *J* = 2.8, 16.8, H–6'), 3.40 (s, 3 H, CH_3O), 3.64 (dd, 1 H, *J* = 3.0, 9.0, H–3), 3.71–3.85 (m, 3 H, H–2, 4, 5), 4.39, 4.57 (d, 1 H, *J* = 11.6, PhCH_2), 4.62, 4.68 (2 d, 2 H, *J* = 12.2, PhCH_2), 4.77 (d, 1 H, *J* = 1.6, H–1), 7.28–7.40 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 21.0 (C–6), 55.2 (CH_3O), 68.3 (C–5), 69.3 (C–4), 71.5, 72.8 (2 Ph*C*H_2), 73.4 (C–2), 79.2 (C–3), 99.2 (C–1), 127.8–137.8 (2 C_6H_5)
15[b]	2254, 1454, 1101, 1028[d]	$CDCl_3$: 2.60 (dd, 1 H, *J* = 7.8, 16.8, H–6), 2.83 (dd, 1 H, *J* = 3.3, 16.8, H–6'), 3.33 (t, 1 H, *J* = 9.0, H–4), 3.36 (s, 3 H, CH_3OCH_2), 3.42 (s, 3 H, CH_3O), 3.51 (dd, 1 H, *J* = 3.6, 9.0, H–2), 3.81 (dq, 1 H, *J* = 3.3, 7.6, H–5), 3.87 (t, 1 H, *J* = 9.0, H–3), 4.56 (d, 1 H, *J* = 3.6, H–1), 4.59, 4.87 (2 d, 2 H, *J* = 6.5, MeOCH_2), 4.63, 4.77 (2 d, 2 H, *J* = 12.2, PhCH_2), 4.70, 4.96 (2 d, 2 H, *J* = 10.9, PhCH_2), 7.29–7.40 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 20.9 (C-6), 55.5, 56.2 (2 CH_3O), 66.1 (C–5), 73.4, 75.7 (2 Ph*C*H_2), 79.1, 79.6, 80.9 (C–2, 3, 4), 97.9 (C–1), 98.5 (MeO*C*H_2), 117.2 (CN), 127.7–137.7 (2 C_6H_5)

Table 4. (continued)

Product[a]	IR (KBr) ν (cm^{-1})	^1H NMR (300 MHz, solvent/TMS) δ, J (Hz)	^{13}C NMR (75 MHz, solvent/TMS) δ
16[b]	2247, 1453, 1125, 1033[d]	$CDCl_3$: 2.67 (dd, 1 H, J = 3.7, 16.7, H–6), 2.96 (dd, 1 H, J = 1.6, 16.7, H–6'), 3.40 (s, 6 H, 2 CH_3O), 3.77–3.82 (m, 4 H, H–2, 3, 4, 5), 4.53, 4.59 (2 d, 2 H, J = 11.7, PhCH_2), 4.68, 4.95 (2 d, 2 H, J = 6.4, MeOCH_2), 4.68, 4.73 (2 d, 2 H, J = 12.7, PhCH_2), 4.75 (d, 1 H, J = 1.0, H–1), 7.28–7.40 (m, 2 H, 2 C_6H_5)	$CDCl_3$: 21.1 (C–6), 55.1, 56.2 (2 CH_3O), 67.7 (C–5), 71.8, 72.8 (2 PhCH_2), 74.0, 76.6, 79.39 (C–2, 3, 4), 98.4 (MeOCH_2), 99.1 (C–1), 117.7 (CN), 127.5–138.0 (2 C_6H_5)
17	3479, 2253, 1496, 1106[d]	$CDCl_3$: 2.63 (dd, 1 H, J = 6.0, 16.7, H–6), 2.76 (dd, 1 H, J = 8.0, 16.7, H–6'), 3.41 (s, 3 H, CH_3O), 3.79 (dd, 1 H, J = 3.6, 9.3, H–2 or H–3), 3.83–3.92 (m, 2 H, H–2 or 3, 4), 4.02 (m, 1 H, H–5), 4.64 (d, 1 H, J = 3.6, H–1), 4.65, 4.81 (2 d, 2 H, J = 12.1, PhCH_2), 4.70, 4.83 (2 d, 2 H, J = 11.5, PhCH_2), 7.35–7.40 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 19.7 (C–6), 55.7 (CH_3O), 65.7, 68.3 (C–4, 5), 73.3, 73.6 (2 PhCH_2), 75.3, 77.1 (C–2, 3), 98.7 (C–1), 117.4 (CN), 128.0–138.5 (2 C_6H_5)
18[b,c]	2253, 1496, 1387, 1038[d]	$CDCl_3$: 2.58 (dd, 1 H, J = 5.3, 16.7, H–6), 2.77 (dd, 1 H, J = 8.5, 16.7, H–6'), 3.41 (s, 3 H, CH_3OH_2), 3.44 (s, 3 H, CH_3OH_2), 3.90–3.92 (m, 2 H, H–2, 3), 3.97 (br s, 1 H, H–4), 4.08 (dd, 1 H, J = 5.3, 8.5, H–4), 4.66, 4.86 (2d, 2 H, J = 12.0, PhCH_2), 4.67 (d, 1 H, J = 2.9, H–1), 4.71, 5.00 (2d, 2 H, J = 6.8, MeOCH_2), 4.72, 4.82 (2 d, 2 H, J = 11.5, PhCH_2), 7.30–7.42 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 55.7 (CH_3O), 56.4 (CH_3OCH_2), 66.2 (C–5), 73.4, 73.6 (2 PhCH_2), 74.0 (C–4), 75.7, 77.7 (C–2, 3), 97.9 (MeOCH_2), 98.7 (C–1), 117.3 (CN), 127.6–138.0 (2 C_6H_5)
19	3381, 3297, 1453, 1372, 1106, 1027	$CDCl_3$: 1.65–1.81 (m, 1 H, H–6), 2.01–2.18 (m, 1 H, H–6'), 3.26 (t, 1 H, J = 9.3, H–4), 3.36, 3.39 (2 s, 6 H, 2 CH_3O), 3.48 (dd, 1 H, J = 3.6, 9.3, H–2), 3.75–3.81 (m, 1 H, H–5), 3.87 (t, 1 H, J = 9.3, H–3), 4.54 (d, 1 H, J = 3.6, H–1), 4.61, 4.93 (2 d, 2 H, J = 6.5, MeOCH_2), 4.63, 4.77 (2 d, 2 H, J = 12.0, PhCH_2), 4.72, 4.96 (2 d, 2 H, J = 11.0, PhCH_2), 7.29–7.4 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 30.7 (C–6), 55.1, 56.4 (2 CH_3O), 61.0 (C–7), 66.6 (C–5), 73.4, 75.7 (2 PhCH_2), 80.0, 80.1, 81.4 (C–2, 3, 4), 97.8 (C–1), 98.5 (MeOCH_2), 127.6–136.0 (2 C_6H_5)
20	3445, 1457, 1369, 1278, 1119, 1035[d]	$CDCl_3$: 1.81–2.00 (m, 1 H, H–6), 2.09–2.20 (m, 1 H, H–6'), 2.45 (s, 1 H, OH), 3.32, 3.37 (2 s, 6 H, 2 CH_3O), 3.70–3.85 (m, 6 H, H–2, 3, 4, 5, 7, 7'), 4.51, 4.57 (2 d, 2 H, J = 11.7, PhCH_2), 4.65, 4.71 (2 d, 2 H, J = 12.4, PhCH_2), 4.67, 4.95 (2 d, 2 H, J = 6.3, MeOCH_2), 7.29–7.40 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 33.8 (C–6), 54.9, 56.4 (2 CH_3O), 60.8 (C–7), 70.9 (C-5), 71.9, 72.9 (2 PhCH_2), 74.4, 76.3, 80.0 (C–2, 3, 4), 98.5 (MeOCH_2), 99.1 (C–1), 127.5–134.0 (2 C_6H_5)
21[b,c]	3448, 1454, 1358, 1260, 1090, 1032[d]	$CDCl_3$: 1.70–1.80 (m, 1 H, H–6), 1.95–2.10 (m, 1 H, H–6'), 3.38–3.41 (2 s, 6 H, 2 CH_3O), 3.75–3.83 (m, 2 H, H–7, 7'), 3.90–3.93 (m, 2 H, H–2, 3), 3.96 (dd, 1 H, J = 1.6, 3.3, H–4), 4.02 (br d, 1 H, J = 3.6, H–5), 4.65, 4.84 (2 d, 2 H, J = 12.0, PhCH_2), 4.66 (d, 1 H, J = 2.7, H–1), 4.69, 5.03 (2 d, 2 H, J = 6.8, MeOCH_2), 4.71, 4.79 (2 d, 2 H, J = 11.5, PhCH_2), 7.28–7.40 (m, 10 H, 2 C_6H_5)	$CDCl_3$: 33.3 (C–6), 55.4, 56.4 (2 CH_3O), 60.7 (C–7), 69.0 (C–5), 73.2, 73.7 (2 PhCH_2), 75.5 (C–4), 76.3, 78.4 (C–2, 3), 97.9 (MeOCH_2), 98.8 (C–1), 127.6–138.4 (2 C_6H_5)

[a] Satisfactory microanalyses obtained: C ± 0.4, H ± 0.2.
[b] Assignments based on 2 D homonuclear (cosy) correlation spectra.
[c] Assignments based on 2 D heteronuclear (C–H) spectra.
[d] Film

Ring opening of the oxetanes **27a**,**b** and **28a**,**b** was carried out at 140 °C in acetic anhydride and using sodium acetate as nucleophile. As expected, the nucleophilic attack happened in a regiospecific fashion to the less hindered primary position leading to the 5,7-di-*O*-acetyl-6-deoxyheptofuranose derivatives **29a**,**b** and **30a**,**b**. While the heptofuranoses **29a** and **30a** were isolated in 90 and 80% yields, respectively, after column chromatography, the 5,7-di-*O*-acetyl-6-deoxy-2,3-*O*-isopropylidene derivatives **29b** and **30b** needed longer reaction times (20–24 h vs 5–6 h) and were isolated in 46 and 45% yields, respectively (Table 5, entries 10–13).

Finally, Zemplén de-*O*-acetylation of compounds **29a**, **30a**, **29b** and **30b** using sodium methoxide in methanol gave 1,2-isopropyliden-3-*O*-benzyl-6-deoxy-α-D-*gluco*- and β-L-*ido*-heptofuranoses **31a** and **32a**, and 6-deoxy-α-D-*manno*- and β-L-*gulo*-heptofuranosides **31b** and **32b**. Compounds **31b** and **32b** were previously synthesized by Zamojski and cowokers[19,20] using acetyliron complex derivatives.

In summary, the results described in this paper show two efficient approaches for the chain elongation of monosaccharides which are very useful for the synthesis of 6-deoxyheptose derivatives. The first one involves the use of 4,6-cyclic sulfate glycopyranoside derivatives as intermediates. These compounds allow a highly regioselective ring opening at carbon 6 by cyanide ion as nucleophile. The second approach involves the regioselective ring expansion of 5,6-anhydro to 5,7-anhydro sugars and subsequent regioselective opening of the resulting oxetane derivatives using acetate as nucleophile.

Table 5. Compounds **23–32** Prepared

Entry	Product[a]	Yield (%)	mp (°C)	$[\alpha]_D^{25}$ (c = 1, $CHCl_3$)	IR (film) ν (cm^{-1})	^1H NMR (300 MHz, $CDCl_3$/TMS) δ, J (Hz)	^{13}C NMR (75 MHz, $CDCl_3$/TMS) δ
1	**23a**	62	syrup	–27	3510, 1354, 1244, 1217, 1179, 1113, 1078, 1029, 967	1.29, 1.43 [2 s, 6 H, $(CH_3)_2C$], 2.84 (br s, 1 H, OH), 4.05–4.23 (m, 4 H, H–3, 4, 5, 6), 4.33 (dd, 1 H, J = 2.5, 10.0, H–6), 4.57 (d, 1 H, J = 3.7, H–2), 4.53, 4.66 (2 d, 2 H, J = 11.6, PhCH_2), 5.85 (d, 1 H, J = 3.7, H–1), 7.20–8.00 (several m, 11 H_{arom}), 8.44 (s, 1 H_{arom})	26.3, 26.8 [(CH_3)$_2$C], 72.4 72.7 (C–6, PhCH_2), 67.4, 79.3, 81.6, 82.1 (C–2, 3, 4, 5), 105.2 (C–1), 112.0 (Me_2C), 126.6–137.1 (Ph, $C_{10}H_7$)
2	**23b**	47	104–105	+ 38.5	3380, 1457, 1355, 1178, 1092[b]	1.28, 1.39 [2 s, 6 H $(CH_3)_2C$], 2.73 (d, 1 H, J = 8.0, OH), 3.23 (s, 3 H, CH_3O), 3.91 (d, 1 H, J = 3.7, 7.9, H–4), 4.16 (m, 1 H, H–5), 4.26 (dd, 1 H, J = 5.7, 10.0, H–6), 4.28 (dd, 1 H, J = 3.0, 10.0, H–6'), 4.54 (d, 1 H, J = 5.9, H–2), 4.78 (dd, 1 H, J = 3.8, 5.9, H–3), 4.85 (s, 1 H, H–1), 7.62–7.73 (m, 2 H_{arom}), 7.89–8.03 (m, 4 H_{arom}), 8.53 (s, 1 H_{arom})	24.6, 25.9 [(CH_3)$_2$C], 54.7 (CH_3O), 71.9 (C-6), 68.2, 78.2, 79.7, 84.7, (C–2, 3, 4, 5), 107.1 (C–1), 112.9 (Me_2C), 122.6–135.4, ($C_{10}H_7$)
3	**24b**	15	syrup	+ 57	3461, 1374, 1090, 1030[b]	1.32, 1.46 [2 s, 6 H, $(CH_3)_2C$], 2.82 (d, 1 H, J = 6.2, OH), 3.30 (s, 3 H, CH_3O), 3.75 (dd, 1 H, J = 5.8, 11.4, H–6), 3.86 (dd, 1 H, J = 3.3, 11.4, H–6'), 3.95 (d, 1 H, J = 3.7, 8.4, H–4), 4.16 (m, 1 H, H–5), 4.57 (d, 1 H, J = 5.9, H–2), 4.84 (dd, 1 H, J = 3.7, 5.9, H–3), 4.89 (s, 1 H, H–1)	24.7, 26.0 [(CH_3)$_2$C], 47.9 (C–6), 54.6 (CH_3O), 69.4, 79.1, 79.7, 84.8 (C–2, 3, 4, 5), 107.1 (C–1), 112.8 (Me_2C)
4	**25a**	67	syrup	– 50	1315, 1290, 1251, 1216, 1164, 1118, 1076, 1030, 948	2.78 (dd, 1 H, J = 2.6, 5.2, H–6), 2.92 (dd, 1 H, J = 3.8, 5.2, H–6'), 3.30 (ddd, 1 H, J = 2.6, 3.8, 7.5, H–5), 3.75 (dd, 1 H, J = 3.2, 7.2, H–4), 4.08 (d, 1 H, J = 3.7, H–3), 4.64 (d, 1 H, J = 3.7, H–2), 4.66, 4.73 (2 dd, 2 H, J = 11.9, PhCH_2), 5.95 (d, 1 H, J = 3.7, H–1), 7.30–7.40 (m, 5 H, C_6H_5)	26.3, 26.8 [(CH_3)$_2$C], 47.0 (C–6), 48.3 (C–5), 72.4, (PhCH_2), 81.8, 82.1, 82.7 (C–2, 3, 4), 105.4 (C–1), 112.0 (Me_2C), 127.7–137.4 (C_6H_5)
5	**25b**[c]	73	syrup	+ 57 (c = 2)	1373, 1211, 1194, 1163, 1102, 1085, 1052, 1026, 990	1.34, 1.49 [2 s, 6 H, $(CH_3)_2C$], 2.79 (dd, 1 H, J = 2.6, 5.2, H–6), 2.92 (dd, 1 H, J = 3.9, 5.2, H–6'), 3.25 (s, 3 H, CH_3O), 3.30 (m, 1 H, H–5), 3.66 (dd, 1 H, J = 3.7, 5.9, H–4), 4.59 (d, 1 H, J = 5.9, H–2), 4.83 (dd, 1 H, J = 3.7, 5.9, H–3), 4.92 (s, 1 H, H–1)	24.8, 26.1 [(CH_3)$_2$C], 46.3 (C–6), 49.0 (C–5), 54.9 (CH_3O), 80.1, 80.3, 85.1 (C–2, 3, 4), 107.5 (C–1), 112.9 (Me_2C)
6	**27a**[d]	86	syrup	– 18	1452, 1215, 1163, 1121, 1075, 1028	1.31, 1.49 [2 s, 6 H, $(CH_3)_2C$], 2.67–2.84 (m, 2 H, H–6, 6'), 3.98 (d, 1 H, J = 3.3, H–3), 4.42–4.67 (m, 6 H, H–2, 4, 7, 7', PhCH_2), 5.03 (m, 1 H, H–5), 5.97 (d, 1 H, J = 3.8, H–1), 7.27–7.33 (m, 5 H, C_6H_5)	24.5 (C–6), 26.3, 26.9 [(CH_3)$_2$C], 69.9 (C–7), 72.0 (PhCH_2), 79.5, 81.7, 82.5, 82.6 (C–2, 3, 4, 5), 105 (C–1), 111.8 (Me_2C), 127.4–137.5 (C_6H_5)
7	**27b**[e]	81	syrup	– 94	1269, 1210, 1163, 110, 1054, 1024, 981, 965	1.27, 1.41 [2 s, 6 H, $(CH_3)_2C$], 2.63–2.74 (m, 1 H, H–6), 2.78–2.90 (m, 1 H, H–6'), 3.37 (s, 3 H, CH_3O), 4.18 (t, 1 H, J = 4.1, H–4), 4.56 (d, 1 H, J = 5.9, H–2), 4.61–4.71 (m, 2 H, H–7,7'), 4.74 (dd, 1 H, J = 3.8, 5.9, H–3), 4.99 (s, 1 H, H–1), 5.08–5.14 (m, 1 H, H–5)	24.5 (C-6), 24.3, 25.7 [(CH_3)$_2$C], 54.7 (CH_3O), 70.0 (C-7), 79.5, 79.9, 81.7, 84.8 (C-2, 3, 4, 5), 107.2 (C-1), 112.5 (Me_2C)
8	**28a**[f]	54	97–98	– 66	1453, 1261, 1210, 1162, 1080, 1027, 974	1.33, 1.50 [2 s, 6 H, $(CH_3)_2C$], 2.37 (m, 1 H, H–6), 2.62 (m, 1 H, H–6'), 3.98 (d, 1 H, J = 3.9, H–3), 4.43–4.64 (m, 3 H, H–4, 7, 7'), 4.38, 4.65 (2 d, 2 H, J =12.2, PhCH_2), 4.62 (d, 1 H, J = 3.9, H–2), 5.04 (q, 1 H, J = 7.0, H–5), 6.02, (d, 1 H, J = 3.9, H–1), 7.28–7.30 (m, 5 H, C_6H_5)	23.8 (C–6), 26.5, 27.0 [(CH_3)$_2$C], 68.8 (C–7), 71.7 (PhCH_2), 80.3, 81.8, 82.7, 83.5 (C–2, 3, 4, 5), 105.6 (C–1), 112.0 (Me_2C), 127.8–137.2 (C_6H_5)

Table 5. (continued)

Entry	Product[a]	Yield (%)	mp (°C)	$[\alpha]_D^{25}$ (c = 1, $CHCl_3$)	IR (film) ν (cm^{-1})	^1H NMR (300 MHz, $CDCl_3$/TMS) δ, J (Hz)	^{13}C NMR (75 MHz, $CDCl_3$/TMS) δ
9	**28b**[e]	93	70–71	+ 41	1379, 1280, 1250, 1234, 1212, 1161, 1096, 1080, 1056, 1026, 979[b]	1.19, 1.34 [2 s, 6 H, $(CH_3)_2C$], 2.43 (dddd, 1 H, J = 7.1, 7.3, 9.1, 11.4, H-6), 4.21 (dddd, 1 H, J = 6.2, 8.0, 8.1, 11.4, H–6'), 4.48 (d, 1 H, J = 6.0, H–2), 4.49–4.55 (m, 1 H, H–7), 4.59–4.67 (m, 1 H, H–7'), 4.68 (dd, 1 H, J = 3.8, 5.9, H–3), 4.87 (s, 1 H, H–1), 4.96 (q, 1 H, J = 7.7, H–5)	24.2 (C–6), 24.7, 25.9 [$(CH_3)_2C$], 54.6 (CH_3O), 68.9 (C–7), 79.3, 80.7, 83.3, 84.8 (C–2, 3, 4, 5), 107.4 (C–1), 112.6 (Me_2C)
10	**29a**[d]	90	syrup	– 44	1741, 1494, 1234, 1163, 1124, 1076, 1029, 890	1.30, 1.47 [2 s, 6 H, $(CH_3)_2C$], 1.91, 1.99 (2s, 6 H, 2 CH_3CO) 2.16–2.24 (m, 2 H, H–6, 6'), 3.91 (d, 1 H, J = 3.3, H–3), 4.04–4.17 (m, 2 H, H–7,7'), 4.19 (dd, 1 H, J = 3.2, 7.7, H–4), 4.43, 4.60 (2 d, 2 H, J = 11.6, PhCH_2), 4.58 (d, 1 H, J = 3.7, H–2), 5.30 (dt, 1 H, J = 3.7, 7.6, H–5), 5.89 (d, 1 H, J = 3.7, H–1), 7.30–7.38 (m, 5 H, C_6H_5)	21.0 (2 CH_3CO), 26.2, 26.8 [$(CH_2)_2C$], 30.4 (C–6), 60.7 (C–7), 72.0 (PhCH_2), 68.1, 80.5, 81.0, 81.7, (C–2, 3, 4, 5), 105.1 (C–1), 111.8 (Me_2C), 128.1–137.0 (C_6H_5), 169.8, 171.0 (2 C=O)
11	**29b**[g]	47	syrup	– 51	1742, 1371, 1236, 1163, 1089, 1051, 1031, 988, 969	1.25, 1.40 [2 s, 6 H, $(CH_3)_2C$], 1.91–2.08 (m, 1 H, H–6), 2.01, 2.02 (2 s, 6 H, 2 CH_3CO), 2.14–2.25 (m, 1 H, H–6), 3.32 (s, 3 H, CH_3O), 3.94 (dd, 1 H, J = 3.7, 7.5, H–4), 4.13 (m, 2 H, H–7,7'), 4.49 (d, 1 H, J = 5.9, H–2), 4.66 (dd, 1 H, J = 3.7, 5.9, H–3), 4.86 (s, 9 H, H–1), 5.22 (dt, 1 H, J = 3.7, 7.6, H–5)	21.0, 21.1 (2 CH_3CO), 24.9, 26.1 [$(CH_3)_2C$], 30.6 (C–6), 54.7 (CH_3O), 60.9 (C–7), 68.8, 79.6, 80.3, 84.7 (C–2, 3, 4, 5), 107.2 (C–1), 112.8 (Me_2C)
12	**30a**[d]	80	syrup	– 28	1741, 1372, 1235, 1166, 1075, 1025, 890, 863	1.33–1.50 [2 s, 6 H, $(CH_3)_2$], 1.75–1.82 (m, 2 H, H–6, 6'), 1.99, 2.03 (2 s, 6 H, 2 CH_3CO), 3.92 (d, 1 H, J = 3.4, H–3), 4.05 (t, 2 H, J = 6.0, H–7, 7'), 4.21 (dd, 1 H, J = 3.5, 8.3, H–4), 4.43, 4.70 (2 d system, 2 H, J = 11.7, PhCH_2), 4.65 (d, 1 H, J = 3.9, H–2), 5.43 (dt, 1 H, J = 3.7, 8.1, H–5), 5.95 (d, 1 H, J = 3.9, H–1), 7.34 (br s, 5 H, C_6H_5)	20.9, 21.2 (2 CH_3CO), 26.3, 26.8 [$(CH_3)_2C$], 29.6 (C–6), 60.2 (C–7), 71.7 (PhCH_2), 69.0, 81.0, 81.8 (C–2, 3, 4, 5), 105.1 (C–1), 111.7 (Me_2C), 128.2–137.2 (C_6H_5), 170.2, 171.4, (2 C=O)
13	**30b**[d]	45	syrup	+ 40	1742, 1235, 1163, 1099, 1051, 1022, 988	1.28, 1.46 [2 s, 6 H, $(CH_3)_2C$], 1.88–2.20 (m, 2 H, H–6, 6'), 2.03, 2.07 (2 s, 6 H, 2 CH_3CO), 3.29 (s, 3 H, CH_3CO), 3.94 (dd, 1 H, J = 3.6, 8.5, H–4), 4.10–4.16 (m, 2 H, H–7, 7'), 4.55 (d, 1 H, J = 5.9, H–2), 4.67 (dd, 1 H, J = 3.6, 5.9, H–3), 4.89 (s, 1 H, H–1), 5.39 (dt, 1 H, J = 3.4, 8.4, H–5)	21.0, 21.1 (2 CH_3CO), 25.1, 26.2 [$(CH_3)_2C$] 29.8 (C–6), 54.6 (CH_3O), 60.5 (C–7), 69.6, 79.6, 80.6, 85.3 (C–2, 3, 4, 5), 106.9 (C–1), 113.0 (Me_2C)
14	**31a**	85	61–62	– 40	3398, 1075[b]	1.32, 14.9 [2 s, 6 H, $(CH_3)_2C$], 1.66–1.78 (m, 1 H, H–6), 1.87–1.97 (m, 1 H, H–6), 2.74, 3.02 (2 br s, 2 H, 2 OH), 3.85 (br s, 2 H, H–7, 7'), 4.04 (dd, 1 H, J = 3.2, 7.7, H–4), 4.10 (d, 1 H, J = 3.2, H–3), 4.13–4.17 (m, 1 H, H–5), 4.63 (d, 1 H, J = 3.7, H–2), 4.56, 4.73 (2 d, 2 H, J = 11.8, PhCH_2), 5.94 (d, 1 H, J = 3.7, H–1), 7.36 (m, 5 H, C_6H_5)	26.3, 26.8 [$(CH_3)_2C$], 35.9 (C–6), 61.4 (C–7), 72.1 (PhCH_2), 69.4, 81.8, 82.1, 82.2 (C–2, 3, 4, 5), 105.1 (C–1), 111.8 (Me_2C), 128.0–137.1 (C_6H_5)
15	**31b**[h]	62	93–94	+ 50	3413, 3334, 1263, 1210, 1191, 1120, 1089, 1047, 1026[b]	1.25, 1.34 [2 s, 6 H, $(CH_3)_2C$], 1.39–1.51 (dddd, 1 H, J = 5.5, 6.0, 9.1, 13.6, H–6'), 1.76–1.87 (dddd, 1 H, J = 2.7, 7.7, 7.7, 13.6, H–6), 3.19 (s, 3 H, CH_3O), 3.52, 3.57 (m, 3 H, H–4, 7,7'), 3.77–3.85 (dddd, 1 H, J = 2.7, 6.5, 6.5, 9.1, H–5), 4.31 (t, 1 H, J = 5.2, OH–7), 4.46 (d, 1 H, J = 5.9, H–2), 4.59 (d, 1 H, J = 6.5, OH–5), 4.71 (dd, 1 H, J = 3.3, 5.9, H–3), 4.77 (s, 1 H, H–1)[i]	24.6, 25.9 [$(CH_3)_2C$], 37.6 (C–6), 53.5 (CH_3O), 57.4 (C–7), 64.4 (C–5), 79.1, 82.1, 84.1 (C–2, 3, 4), 106.3 (C–1), 111.1 (Me_2C)[i]

Table 5. (continued)

Entry	Product[a]	Yield (%)	mp (°C)	$[\alpha]_D^{25}$ (c = 1, $CHCl_3$)	IR (film) ν (cm^{-1})	^1H NMR (300 MHz, $CDCl_3$/TMS) δ, J (Hz)	^{13}C NMR (75 MHz, $CDCl_3$/TMS) δ
16	**32a**	76	75–76	– 50 (c = 0.5)	3435, 1255, 1209, 1161, 1139, 1107, 1027[b]	1.49, 1.33 [2 s, 6 H, $(CH_3)_2C$], 1.52–1.60 (m, 1 H, H–6), 1.70–1.80 (m, 1 H, H–6'), 3.26, 3.80 (2 br s, 2 H, 2 OH), 3.78 (m, 2 H, H–7, 7'), 3.97 (d, 1 H, J = 3.5, H–3), 4.06 (dd, 1 H, J = 3.5, 5.6, H–4), 4.19 (m, 1 H, H–5), 4.45, 4.71 (2 d, 2 H, J = 11.8, PhCH_2), 4.65 (d, 1 H, J = 3.8, H–2), 5.98 (d, 1 H, J = 3.8, H–1), 7.28–7.40 (br s, 5 H, C_6H_5)	26.3, 26.8 [(CH_3)$_2$C], 34.8 (C–6), 60.8 (C–7), 71.9 (PhCH_2), 69.7, 82.2, 82.6 (C–2, 3, 4, 5), 104.9 (C–1), 111.8 (Me_2C), 128.0–137.2 (C_6H_5)
17	**32b**[j]	80	56–57	+ 68	3430, 1211, 1164, 1100, 1093, 1052, 1022, 987[b]	1.23, 1.33 [2 s, 6 H, $(CH_3)_2C$], 1.43–1.55 (m, 1 H, H–6), 1.63–1.73 (m, 1 H, H–6), 3.22 (s, 3 H, CH_3O), 3.43–3.61 (m, 2 H, H–7, 7'), 3.65 (dd, 1 H, J = 3.2, 8.5, H–4), 3.72–3.80 (m, 1 H, H–5), 4.33 (t, 1 H, J = 5.2, OH–7), 4.47 (d, 1 H, J = 5.9, H–2), 4.62 (d, 1 H, J = 5.2, OH–5), 4.68 (dd, 1 H, J = 3.3, 5.9, H–3), 4.80 (s, 1 H, H–1)[i]	25.9, 24.5 [$(CH_3)_2C$] 35.5 (C–6), 53.6 (CH_3O), 57.6 (C–7), 66.5 (C–5), 79.2, 83.4, 84.4 (C–2, 3, 4), 106.0 (C–1), 111.2 (Me_2C)[i]

[a] Satisfactory microanalyses obtained: C ± 0.4, H ± 0.2.
[b] Recorded as KBr pellet.
[c] Similar treatment using **24b** as starting material gave **25b** (72%).
[d] Purified on silica gel using Et_2O/hexane (1:1) as solvent.
[e] This compound was not stable on silica gel and the resulting product was spectroscopically pure.
[f] Crystallized from Et_2O/hexane.
[g] Purified on silica gel using Et_2O/hexane (4:1) as solvent.
[h] Lit.[20] mp 94–95 °C; Lit.[20] $[\alpha]_D$ + 58.8.
[i] Recorded in DMSO-d_6
[j] Lit.[19] mp 55–57 °C; Lit.[19] $[\alpha]_D$ +67.5 (c = 1.4, $CHCl_3$).

TLC was performed on Merck Silica Gel 60 F_{254} aluminium sheets with detection by charring with H_2SO_4, and by UV light when applicable. Flash and column chromatography was performed on silica gel Scharlau (230–400 mesh, ASTM) and Merck (70–230 mesh, ASTM). Melting points were measured on a Büchi melting point apparatus and a Reichter hotplate microscope and are uncorrected. Elemental analyses were carried out with Perkin-Elmer 240C instrument. Optical rotations were recorded on a Perkin-Elmer 141 polarimeter at r.t. IR spectra were recorded on a Perkin-Elmer 983G. ^1H and ^{13}C NMR spectra were recorded on a Bruker AM 300, and 400 MHz spectrometer. Chemical shifts are given in ppm and referenced to internal TMS (δ_H, δ_C 0.00). J values are given in Hz.

Cyclic sulfates **1**, **2**, **4** and **5** were prepared from methyl 2,3-di-*O*-acetyl-α-D-glucopyranoside,[21] methyl 2,3-di-*O*-acetyl-α-D-mannopyranoside (prepared from methyl 2,3-di-*O*-acetyl-4,6-*O*-benzylidene-α-D-mannopyranoside[22]), methyl 2,3-di-*O*-benzyl-α-D-mannopyranoside,[23] and methyl 2,3-di-*O*-benzyl-α-D-galactopyranoside,[24] respectively, following the procedure of Gao and Sharpless[15] (seeTable 1 for yields and physical data).

Preparation of Compounds 7–12 by Reaction of Lithium or Sodium Cyanide with Cyclic Sulfate Sugars; General Procedure:
To a solution of the cyclic sulfate **1–6** in anhyd DMF (2 mL) or anhyd acetone (20 mL) was added LiCN or NaCN. The resulting solution or suspension was then stirred at r.t. until no cyclic sulfate remained (TLC). The solution was then concentrated, and the product was purified by flash cromatography on silica gel (see Table 2, entries 1–7 for reaction conditions and yields and Table 4 for physical data).

Hydrolysis of the Lithium Sulfates 9–11; General Procedure:
To a solution of compound **9–11** in THF/H_2O was added concd H_2SO_4. The reaction mixture was stirred until no sulfate remained (TLC), then diluted with Et_2O, washed with aq satd $NaHCO_3$ solution and H_2O, dried ($MgSO_4$), and concentrated. The product was purified by flash cromatography on silica gel (see Table 2, entries 8–10 for reaction conditions and yields and Table 4 for physical and spectroscopic data).

Methoxymethylation of Compounds 13, 14 and 17; General Procedure:
To a vigorously stirred solution of compound **13**, **14** and **17** in CH_2Cl_2 and dimethoxymethane at r.t. was added portionwise P_2O_5 until completion of the reaction. The solid residue was removed by decantation and washed with CH_2Cl_2. The combined CH_2Cl_2 solutions were washed with aq satd $NaHCO_3$ solution and H_2O, dried (K_2CO_3), concentrated, and the product was purified by flash chromatography on silica gel (see Table 2, entries 11–13 for reaction conditions and yields and Table 4 for physical and spectroscopic data).

Reduction of the Nitriles 15, 16 and 18; General Procedure:
To a solution of compounds **15**, **16** and **18** in anhyd toluene at 0 °C was added DIBAH (1 M in hexane or THF). The reaction mixture was stirred until no nitrile remained (TLC). Then MeOH and aq 2 M HCl were added, the mixture was stirred for 45 min and filtered. The aqueous layer in the filtrate was extracted with Et_2O, and the combined organic layers were washed with 2 M HCl, aq satd $NaHCO_3$ solution and H_2O, dried, and concentrated. $NaBH_4$ was added to the crude product in MeOH, and the solution was stirred at r.t. for 0.5–1.5 h. Processing of the mixture by treatment with acetone to destroy the excess of hydride and evaporation with several portions of added

MeOH gave a residue that was diluted with Et_2O and then washed successively with aq 2 M HCl, satd $NaHCO_3$ solution and H_2O, dried ($MgSO_4$) and concentrated to give a product that was purified by flash cromatography on silica gel (see Table 3 for reaction conditions and Table 4 for physical and spectroscopic data).

Reaction of Furanosides 22a,b with 2-Naphthalenesulfonyl Chloride; General Procedure:
To a stirred solution of **22a,b**[17,18] (15 mmol) in pyridine (15 mL) was slowly added 2-naphthalenesulfonyl chloride (2.7 equiv for **22a**, and 1.4 equiv for **22b**) at 0°C. After 20–24 h at r.t., H_2O (50 mL) was added and the mixture extracted with $CHCl_3$ (100 mL). The organic layer was washed successively with 5% aq HCl (2 × 75 mL), aq satd $NaHCO_3$ solution (100 mL) and H_2O (50 mL). Then the organic solution was dried ($MgSO_4$), concentrated and the resulting residue was chromatographed on silica gel (Et_2O/hexane 3:1 for **23a**, and EtOAc/hexane 1:1 for **23b**) (see Table 5, entries 1 and 2).

5,6-Anhydro Compounds 25a,b; General Procedure:
To a solution of compounds **23a,b** (7.5 mmol) in anhyd MeOH/$CHCl_3$ (2:1, 30 mL) was added a solution of sodium (2.3 equiv for **23a**, and 4.1 equiv for **23b**) in MeOH (15 mL). The reaction mixture was stirred at r.t. for 2 h. An aq 20% solution of NH_4Cl (75 mL) was added, the MeOH was evaporated, and the residue extracted with EtOAc (2 × 100 mL). The organic layer was dried ($MgSO_4$), concentrated and the crude product was purified by column chromatography (Et_2O/hexane 1:1 for **23a**, and Et_2O/hexane 1:3 for **23b**) (Table 5, entries 4 and 5). Similar treatment using the 6-deoxy-6-chloro derivative **24b** as starting material gave **25b** (72%).

Synthesis of Oxetanes 27a,b and 28a,b; General Procedure:
To a stirred solution of trimethylsulfoxonium iodide (4.1 mmol) in *t*-BuOH (8 mL) was added KOBu-*t* (4.1 mmol) at 50°C. After 30 min, oxirane **25a,b** and **26a,b**[17,18] (1.37 mmol) in *t*-BuOH (8 mL) was added, and the stirring was continued at the same temperature until TLC (Et_2O/hexane, 2:1) showed complete disappearance of the starting material (6–20 h). The solvent was carefully evaporated under reduced pressure and H_2O (50 mL) was added to the residual suspension. The mixture was extracted with Et_2O (2 × 50 mL), and the combined organic solutions were dried ($MgSO_4$) and concentrated. Crude **27a** was purified by a short column chromatography (Et_2O/hexane, 1:1). Compounds **28a** crystallized from Et_2O/hexane. Compounds **27b** and **28b** were not stable upon treatment with silica gel and were used directly in the next step as they showed to be spectroscopically pure (see Table 5, entries 6–9).

6-Deoxyheptoses 29a,b and 30a,b by Ring Opening of Oxetanes 27a,b and 28a,b; General Procedure:
A mixture of **27a,b** or **28a,b** (6.5 mmol) and anhyd NaOAc (6 g) in Ac_2O (25 mL) and AcOH (2 mL) was heated at 140°C until TLC (Et_2O/hexane 2:1 for **27a** and **28a**; Et_2O/hexane 4:1 for **27b** and **28b**) showed complete disappearance of the starting material (7–48 h). After cooling, the mixture was dissolved in CH_2Cl_2 (150 mL) and washed successively with aq satd $NaHCO_3$ solution (3 × 150 mL) and H_2O (100 mL). The organic layer was dried (Na_2SO_4) and the solvent removed under reduced pressure giving a crude product that was purified by column chromatography (Et_2O/hexane 1:1 for **29a** and **30a** and Et_2O/hexane 4:1 for **29b** and **30b**) (see Table 5, entries 10–13).

Zemplén De-*O*-acetylation of 29a,b and 30a,b; General Procedure:
A solution of the corresponding acetyl derivative **29a,b** or **30a,b** (1 mmol) in anhyd MeOH (30 mL) containing NaOMe (10 mg, 0.18 mmol) was kept at r.t. for 1 h, deionized with Amberlite IR-120 (H^+) (2 g) and the solvent evaporated. The residue was purified on silica gel using EtOAc as solvent (see Table 5, entries 14–17).

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