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Synthesis and Characterization of Sulfated Gal-β-1,3/4-GlcNAc Disaccharides through Consecutive Protection/Glycosylation Steps

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Abstract: We have developed an expeditious procedure to yield large amounts of orthogonally protected Gal-β1,3/4-GlcNAc, which allowed for the systematic introduction of a sulfate group onto the C3/C6 positions of Gal and/or the C6 position of GlcNAc. In particular, the disaccharide precursors were prepared in five or six steps and high overall yield from *para*-tolyl-6-*O*-*tert*-butyldiphenylsilyl-1-thio-β-D-galactopyranoside. After deprotection and sulfation steps, the final products were characterized by using several NMR methods to unambiguously confirm the location of each introduced sulfate group and they were examined for their binding specificity of human galectin-1 and galectin-8.

Keywords: carbohydrates · galectin · glycosylation · protecting groups · sulfates

Introduction

Sulfate-containing glycans are involved in myriad physiological processes, including cell morphogenesis and development, viral invasion, tumor metastasis, inflammation, and neural disorders.[1] For instance, the sulfated forms of α2,3-sialylated, α1,3-fucosylated glycans, such as the sialyl Lewis x determinant, are essential for recognition by L-selectin (a calcium-ion-dependent lectin that is expressed in most leukocytes).[2] Sulfation often occurs at the O6 position of a Gal or GlcNAc residue. Lymphocytes in mice that lack the two sulfotransferases that are responsible for sulfation cannot target high endothelial venules.[2] Several carbohydrate-binding proteins, including selectins and galectins (β-galactoside-binding lectins), have been shown to bind sulfated sugars.[3] However, the structure–activity relationships in sulfated glycans are unclear, that is, it is important to elucidate how the specific position of a sulfate affects the binding and activity of the corresponding receptors (lectins). Several groups have prepared sulfated carbohydrates. For example, the groups of Hsieh–Wilson and Mallet prepared chondroitin sulfate (CS) oligosaccharides and their analogues to access their functional role in the modulation of neuron growth and binding interactions with hepatocyte growth-factor/scatter-factor and CXCL12 (a GAG-binding protein).[4] Others have established efficient methods for the synthesis of heparin and heparan sulfate oligosaccharides.[5–9] Kiso and co-workers were the first to synthesize 6-sulfo sialyl Lewis x gangliosides and analogues as potent L-selectin ligands. Pratt and Bertozzi recently established divergent chemoenzymatic syntheses for a similar purpose.[10]

Laborious protection/deprotection steps are major impediments to the development of efficient methods for the synthesis of carbohydrates.[11] Specifically, the design of protection/deprotection steps that involve sulfated sugars is troublesome because sulfates are labile and must be added at a late stage in the synthesis. If sulfates are to be added at different sites on a sugar, different synthetic precursors and protection strategies must be employed, which inevitably lengthens the procedure. Herein, we report efficient syntheses of fully protected Gal-β1,3/4-GlcNAc disaccharides by using consecutive protection and glycosylation steps. Subsequent deprotection and sulfation steps afforded two non-sulfated and six mono-sulfated saccharides (compounds **1**–**8**, Scheme 1). We introduced a sulfate group onto the C3 or C6 positions of Gal, or the C6 position of GlcNAc, either of which could be found at the non-reducing terminus of N- or O-glycans. These glycan products were further examined for their binding interactions with human galectins-1 and -8.

Our aim was to prepare common disaccharide precursors that contained orthogonal protecting groups, which would allow for the incorporation of one or more sulfate groups at the desired position(s) and allow the prompt assembly of

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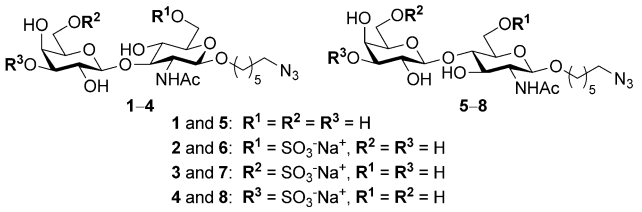


Scheme 1. Structures of target disaccharides **1**–**8**.

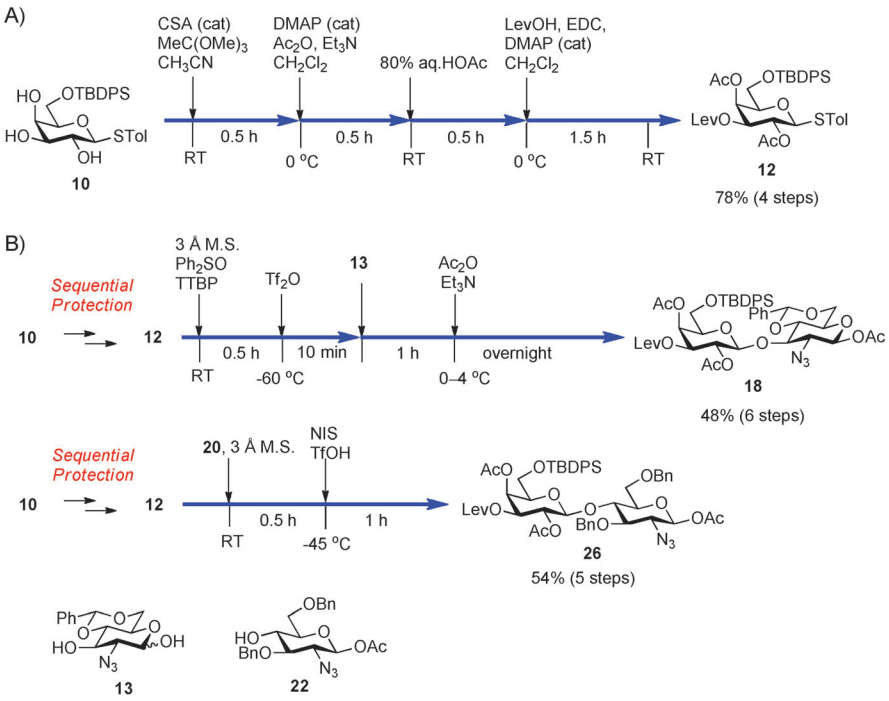
longer glycan chains by rapidly converting the disaccharide precursors into glycosyl donors and acceptors. The modular construction of orthogonally protected disaccharides has greatly simplified and accelerated these synthetic processes.[7a,12]

Results and Discussion

The primary hydroxy group of *para*-tolyl-1-thio-β-D-galactopyranoside (which was directly derived from peracetate **9**) was masked by the formation of the *tert*-butyldiphenylsilyl (TBDPS) ether.[13] Then, the product (**10**) was reacted with trimethyl orthoacetate in the presence of a catalytic amount of camphor sulfonic acid (CSA) to form orthoesters at the C3 and C4 hydroxy groups. The resulting product was subjected to acetylation and selective unmasking of the C3-hydroxy group under acidic conditions to generate compound **11** (87% yield). Further esterification with levulinic acid at the O3 position afforded the fully protected thiogalactoside **12** (94% yield). Because the reaction conditions that were used to form compound **12** from compound **10** were compatible, the four-step synthesis was performed consecutively without chromatographic purification of the intermediate products and it was only interrupted by the removal of that solvents and a simple workup between each reaction (Scheme 2A). After final purification, compound **12** was obtained in 78% yield (>50 g). Similar procedures have been reported for the preparation of elaborated gluco-, glucosamino-, galacto-, and digitoxosides.[14]

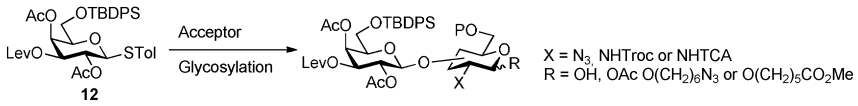
Our orthogonal protection strategy offers several advantages in the subsequent syntheses. In general, regio- and stereoselective glycosylations can be achieved by the introduction of various protecting groups. The O3 and O6 positions of Gal are protected as their TBDPS ether and Lev ester (i.e., compound **12**), respectively, thus making it possible to specifically introduce a sulfate group in a later stage of the synthesis. Acetylation at the O2 position was essential for controlling the stereoselectivity during the glycosylation reaction, thus resulting in the formation of a 1,2-*trans*-glycosidic bond. Moreover, we also prepared glycosyl acceptors with different protecting groups (Table 1), including amino groups at the C2 position and 4,6-benzylidene (for β1,3-glycosylation) and 3,6-dibenzyl ether groups (for β1,4-glycosylation). These protecting groups are commonly used in carbohydrate chemistry and can be selectively removed.[7b,8c,d] Because three protecting groups are installed on the donor and two/three groups are installed on acceptors (Table 1), it is necessary to optimize these glycosylation reactions.

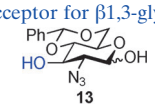
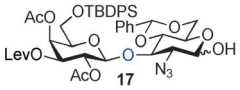
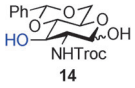
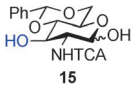
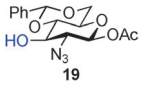
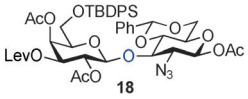
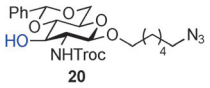
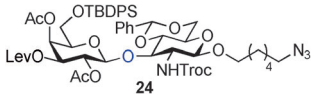
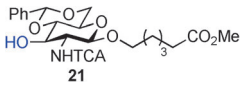
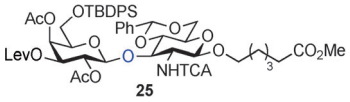
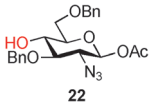
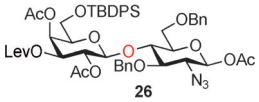
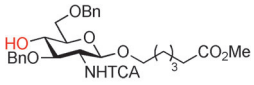
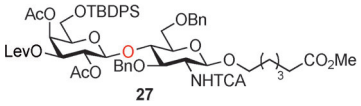
To optimize the glycosylation reaction of compound **12**, we prepared several glucosamine-type acceptors.[15] Compound **12** was activated by using Ph_2SO, 2,4,6-tri-*tert*-butylpyrimidine (TTBP), and Tf_2O, mainly for β1,3-glycosylation (Table 1, conditions A). The same compound was treated with *N*-iodosuccinimide (NIS) and TfOH to form a β1,4-glycosidic bond (conditions B). Several acceptors gave moderate-to-good yields, despite the presence of different amino-protecting groups at the C2 position, including azido (N_3), 2,2,2-trichloroethoxycarbonyl (Troc), and trichloroacetyl (TCA) groups (Table 1). Interestingly, among the four acceptors that we examined (compounds **13**–**16**; Table 1, entries 1–5), only compound **13** was successfully glycosylated with compound **12** to generate compound **17** in 86% yield under the preactivation conditions. The O3-Lev protection



Scheme 2. Consecutive operations in the syntheses of A) thiogalactoside **12** and B) β1,3-disaccharide **18** and β1,4-disaccharide **26**. Each thick, blue arrow represents one reaction. M.S. = molecular sieves.

Table 1. Glycosylation reactions of β-galactosyl donor **12** with several GlcNAc-type acceptors.



Entry	Acceptor	Glycosylation conditions[a]	Product	Yield [%][b]
3-OH acceptor for β1,3-glycosylation				
1	 **13**	A	 **17**	86
2	 **14**	A		–[c]
3	**14**	B		–[c,d]
4	 **15**	A		–[c]
5	 **16**	A		–[c]
6	 **19**	A	 **18**	56
7	**19**	A	**18**	70
8	 **20**	B	 **24**	71
9	 **21**	A	 **25**	57
10	**21**	B	**25**	77
4-OH acceptor for β1,4-glycosylation				
11	 **22**	A	 **26**	80
12	**22**	B	**26**	84
13	 **23**	B	 **27**	71

[a] Glycosylation conditions: A) Ph_2SO, Tf_2O, TTBP, 3 Å M.S., CH_2Cl_2/toluene/MeCN or CH_2Cl_2, −60 °C, 1 h; B) NIS/TfOH, CH_2Cl_2, 3 Å M.S. (for temperature and reaction time, see the Experimental Section). [b] Yield of isolated product. [c] No glycosylated product was formed, owing to the hydrolysis of donor **12**. [d] The acceptor (**14**) was even insoluble in MeCN and 1,4-dioxane.

of compound **12** appeared to be critical because the O3-acetate analogue only gave low yields in the glycosidation reactions, owing to the accompanying side reactions of acetyl transfer or donor hydrolysis.[14f,16] In the reactions of acceptors **14**–**16**, we observed significant hydrolysis of donor **12**. One possible explanation of this result is the poor solubility of these acceptors. We had no success on trying to dissolve these compound in several different solvents (such as CH_2Cl_2, MeCN, 1,4-dioxane, and the mixture CH_2Cl_2/toluene/MeCN).

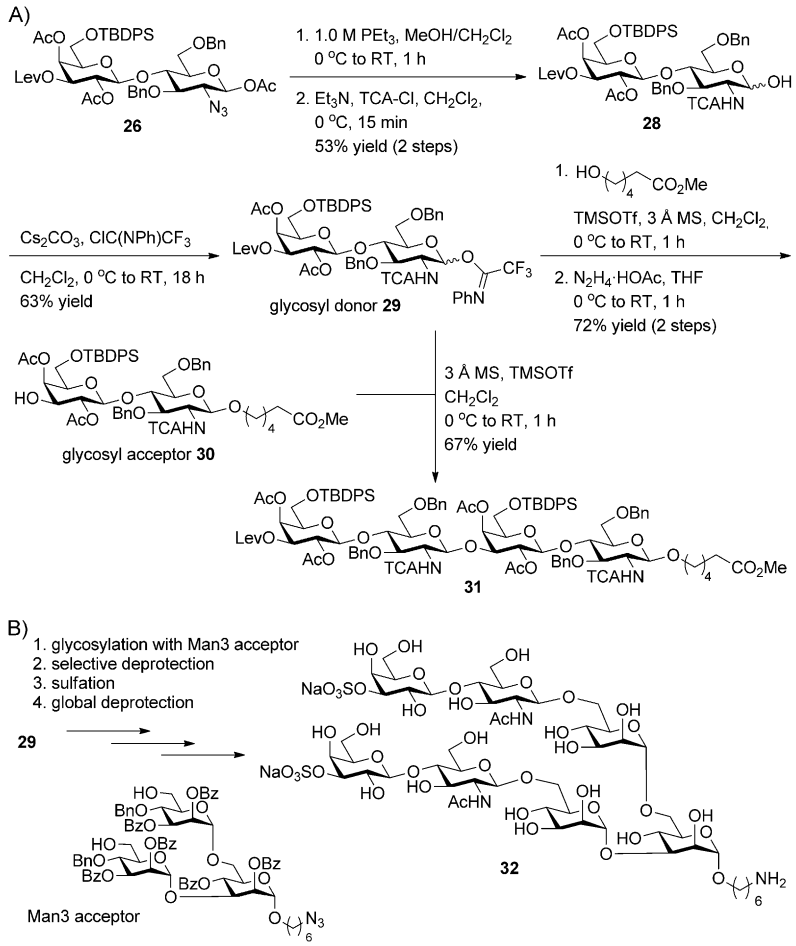
For convenient product characterization, the reaction in Table 1, entry 1 was followed by β-selective acetylation to afford compound **18** in 80% yield (2 steps). This preactivation method was also applied to the synthesis of acetate analogue **19** (Table 1, entry 6), albeit in a lower yield. Compound **22**, which was directly derived from compound **13** in three steps,[8d,17] was coupled with compound **12** under the same glycosylation conditions (Table 1, entry 11) in 80% yield, whereas the use of NIS/TfOH as a promoter afforded the product in 84% yield (Table 1, entry 12). Acceptors that contained a linker at the reducing terminus (**20**, **21**, and **23**) were also tolerated in the glycosylation reactions to afford their corresponding disaccharides in good yields (Table 1, entries 8, 9, and 13).

The results listed in Table 1 show several useful findings. First, galactosyl donor **12** successfully reacted with six different acceptors that were protected with two/three different protecting groups. Second, better yields were obtained under conditions B compared to those under conditions A (Table 1, entries 6, 7, 9–12). In addition, compound **13** was a diol and its corresponding glycosylation reaction showed complete regioselectivity at the O3 position. The possible reaction mechanism is different from that reported for the base-mediated esterification reaction.[18] When donor **12** forms the oxocarbenium intermediate through the preactivation method, the 3-OH group of diol **13** can reacts with the intermediate to produce compound **17** because of its higher nucleophilicity than that of hemiacetal-OH group. In contrast, the base-mediated esterification reaction was found to predominantly occur at the hemiacetal-OH group. The hydroxy group has a higher tendency for deprotonation under basic conditions, likely owing to its lower pK_a value. Note that compound **17** is fully characterized (see the Experimental Section and the Supporting Information, S22–28) and, in its HMBC spectrum, the resonance of the C3 atom

of the GlcNAc group correlates with the H1′ atom of the Gal group (^3J(C,H) coupling) and vice versa.

Thus, we selected compounds **13** and **22**[19] for further investigation. More than 50 g of each of compounds **12**, **13**, and **22** could be obtained in an effective manner. The aforementioned synthesis of compound **12** was combined with each of the β1,3- and β1,4-glycosylation reactions so that disaccharides **18** and **26** were synthesized in successive operations starting from compound **10** (Scheme 2B). As a consequence, compound **18** was obtained in 48% yield (6 steps) and compound **26** was obtained in 54% yield (5 steps).

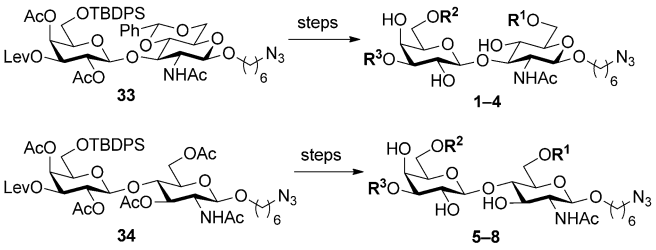
Furthermore, our synthetic method can also be extended to the construction of longer-chain oligosaccharides in an efficient manner by using modular glycosyl donors and acceptors. For example, disaccharide **26** can be converted into donor **29** and acceptor **30** (Scheme 3A). Triethyl phosphine (PEt_3) was utilized to reduce the azide at the C2 position and to hydrolyze the anomeric acetate at the same time, followed by selective *N*-trichloroacetylation (to give compound **28**) and 1-*O*-imidation to afford glycosyl donor **29**. Notably, the glycosylation reaction that involved compounds **29** and **30** in the presence of TMSOTf afforded tetrasaccharide **31** in 67% yield without further optimization. In comparison with other published syntheses of Gal-β1,4-GlcNAc-repeating oligosaccharides,[20] our method not only decreases the time that is needed to prepare a variety of disaccharide precursors, but also incorporates orthogonal protecting groups that meet the requirement to modify the sugars, for example, by sulfation or oxidation, at a specific position(s). In addition, we have achieved an eight-step synthesis of biantennary heptasaccharide **32**, in which the major step was the glycosidation of donor **29** with a trimannoside acceptor (Scheme 3B).[21]



Scheme 3. A) Synthesis of tetrasaccharide **31** from the disaccharide precursor (**26**). B) Application of disaccharide donor **29** to the synthesis of heptasaccharide **32**.

The conversion of β1,3- and β1,4-disaccharides **33** and **34** into non-sulfated (**1** and **5**) and mono-sulfated compounds (**2**–**4** and **6**–**8**), respectively, was easily achieved by using various combinations of deprotection and sulfation steps (Scheme 4). For instance, compound **3**, which contained a sulfate group at the C6 position of the Gal moiety was derived from compound **33** through the following five steps:[22] The treatment of compound **33** with an 80% aqueous solution of AcOH at 50°C removed the benzylidene protecting group to afford the free diol and was followed by acetylation (in the presence of pyridine, Ac_2O, and a catalytic amount of dimethylaminopyridine). The next two steps involved cleavage of the silyl ether (treatment with TBAF) and sulfation by using $NMe_3{\cdot}SO_3$. Finally, NaOMe/MeOH was used to simultaneously remove the acetate and levulinate ester groups to afford compound **3** in 39% overall yield in five steps. The other disaccharides were obtained in a similar manner. Moreover, it was not trivial to purify these final sulfated products. When using column chromatography on silica gel, ammonium hydroxide or triethylamine was added to the eluent ($CHCl_3$/MeOH or EtOAc/MeOH) to avoid delayed retention of the desired product. Excessive salts can be removed by means of a Zeba spin desalting column. Ion-exchange chromatography was performed on a Hitrap Q column to obtain the product or the desired counterion in high purity.

All of the final products (**1**–**8**) were characterized in detail by using several NMR experiments, including ^{1}H-^{1}H



reactant	sequence of reaction steps	final product
33	a, b, c	**1** ($R^1 = R^2 = R^3 = H$)
34	b, c	**5** ($R^1 = R^2 = R^3 = H$)
33	a, d, b, c	**2** ($R^1 = SO_3^-Na^+$, $R^2 = R^3 = H$)
34	c, d, b	**6** ($R^1 = SO_3^-Na^+$, $R^2 = R^3 = H$)
33	a, e, b, d, c	**3** ($R^2 = SO_3^-Na^+$, $R^1 = R^3 = H$)
34	b, d, c	**7** ($R^2 = SO_3^-Na^+$, $R^1 = R^3 = H$)
33	a, b, e, f, d, c	**4** ($R^3 = SO_3^-Na^+$, $R^1 = R^2 = H$)
34	b, e, f, d, c	**8** ($R^3 = SO_3^-Na^+$, $R^1 = R^2 = H$)

Scheme 4. Compounds **1**–**8** were obtained by using different combinations of deprotection and sulfation steps: a) 80% AcOH, 50°C; b) 1.0 M TBAF in THF, AcOH, THF, 0°C to RT; c) MeONa, MeOH, RT; d) SO_3·TMA, DMF, RT or 50°C; e) pyridine, Ac_2O, cat. DMAP, 0°C to RT; f) N_2H_4·AcOH, THF, 0°C to RT.

COSY, ^{1}H-^{13}C HMQC, 1D-selective TOCSY, and DEPT NMR spectroscopy. In general, the anomeric protons of these products were identified first because they appeared as the most downfield-shifted signals in the ^{1}H NMR spectra. The HMBC method can be applied to pinpoint the H1 proton of GlcNAc, because only this proton correlates with those of the 6-azidohexyl group (the reducing-end linker). The subsequent use of ^{1}H-^{13}C HMQC is useful to not only confirm the previous assignment but also to identify/distinguish between the two anomeric carbon atoms. ^{1}H-^{1}H COSY, in conjunction with 1D-selective TOCSY, is able to assign all of the protons (Figure 1A). In particular, for sulfated disaccharides **2**–**4** and **6**–**8**, the desirable position of each sulfate was rigorously determined. For instance, compound **7** had a sulfate group at the C6 position of the Gal moiety. The corresponding protons (H6a and H6b) appeared at $\delta = 4.20$ and 4.16 ppm, which were 0.48–0.52 ppm downfield shifted in comparison with those of its non-sulfated analogue (**5**, Table 2). Likewise, the sulfated carbon atom of compound **7** had a chemical shift of $\delta = 68.1$ ppm, which was 5.4 ppm higher than that of compound **5** (Figure 1B and Table 2). The trend of higher chemical shifts was observed in all of the sulfated carbon atoms and their adjacent protons (Figure 1).

Furthermore, compounds **1**–**8** were examined for their lectin-binding specificities, in which we employed the previously developed AlphaScreen method, which employed in-solution proximity binding to photosensitizers,[23] for qualitative measurements (the major reagents were commercially available from Perkin–Elmer Inc.). Human galectins-1 and

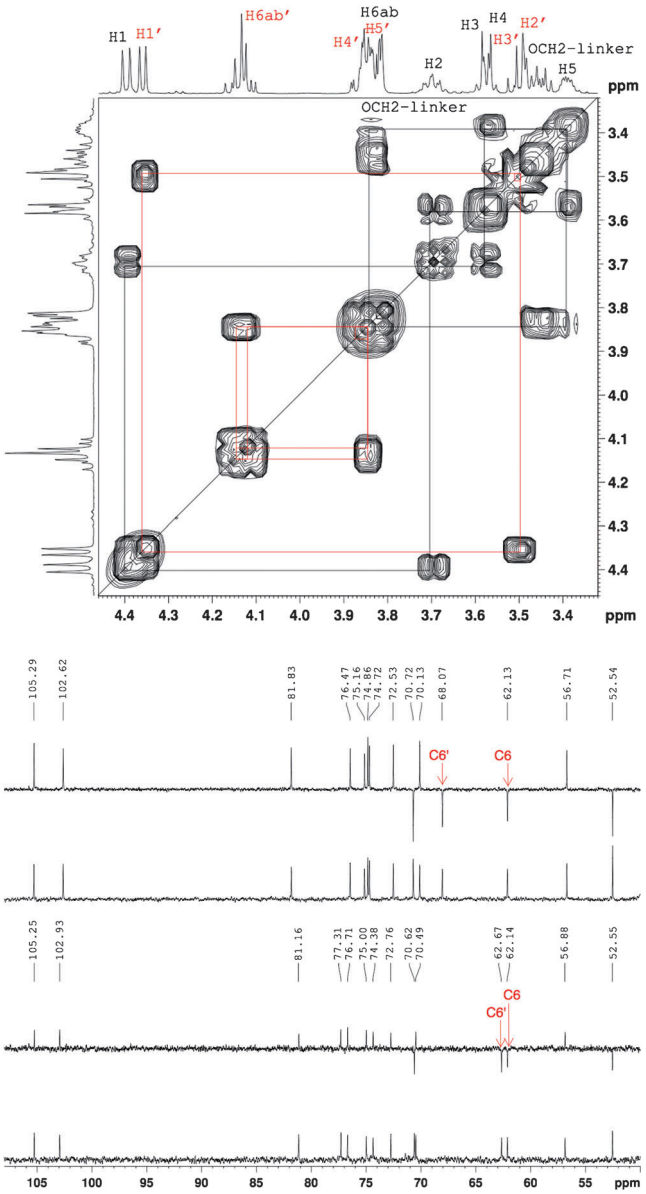


Figure 1. A) All of the protons of the Gal and GlcNAc groups in compound **7** were assigned by ^{1}H-^{1}H COSY NMR spectroscopy. The red and black lines connect the Gal and GlcNAc resonances, respectively. B) A comparison of the ^{13}C NMR and the corresponding DEPT-135 spectra of compound **7** (top two spectra) and its non-sulfated analogue (**5**, bottom two spectra). Only a region of the spectra is shown to include the signals of the carbon atoms of the sugar ring.

-8 were utilized as the counterparts because they represent two main galectin groups, that is, galectin-1, as a prototypical galectin, whereas galectin-8 is a tandem-repeat galectin.[2] Both galectins are essential for the differentiation of mature B cells into immunoglobulin-secreting plasma cells.[24] The preliminary result of binding analysis showed two interesting features: First, that the incorporation of a sulfate group at a specific position of Gal-β1,3/4-GlcNAc increased the binding of galectin. Compounds **4** and **8**, which contained a sulfate group at the C3 position of Gal, bound more tightly to galectin-1 than their respective non-sulfated analogues (**1**

Table 2. Proton (top) and carbon (bottom) chemical shifts of Gal/GlcNAc in the final compounds **1**–**8**.[a]

	δ (^{1}H NMR) [ppm] of Gal							δ (^{1}H NMR) [ppm] of GlcNAc						
	H1′	H2′	H3′	H4′	H5′	H6a′	H6b′	H1	H2	H3	H4	H5	H6a	H6b
1	4.23	3.50	3.42	3.76	3.51	3.72	3.65	4.44	3.66	3.63	3.37	3.26	3.84	3.62
2	4.28	3.54	3.57	3.81	3.50	3.77	3.70	4.47	3.75	3.70	3.62	3.55	**4.41**	**4.10**
3	4.31	3.54	3.50	3.87	3.86	**4.18**	**4.17**	4.45	3.77	3.68	3.40	3.32	3.88	3.73
4	4.42	3.66	**4.19**	4.19	3.61	3.75	3.67	4.46	3.75	3.71	3.40	3.30	3.85	3.71
5	4.33	3.49	3.43	3.76	3.53	3.72	3.64	4.36	3.65	3.58	3.56	3.35	3.86	3.80
6	4.50	3.52	3.51	3.82	3.63	3.76	3.69	4.41	3.71	3.63	3.62	3.63	**4.36**	**4.30**
7	4.40	3.53	3.55	3.87	3.89	**4.20**	**4.16**	4.44	3.75	3.63	3.61	3.43	3.92	3.88
8	4.49	3.72	**4.24**	4.22	3.64	3.76	3.69	4.39	3.72	3.64	3.62	3.40	3.92	3.87
	δ (^{13}C NMR) [ppm] of Gal							δ (^{13}C NMR) [ppm] of GlcNAc						
	C1′	C2′	C3′	C4′	C5′	C6′	C1	C2	C3	C4	C5	C6		
1	105.7	72.5	74.8	70.4	77.3	62.6	102.5	56.5	85.1	70.7	77.7	62.9		
2	105.7	72.5	74.8	70.4	77.7	62.6	102.5	56.5	85.1	70.7	77.2	**68.7**		
3	105.7	72.3	74.5	74.8	70.0	**67.9**	102.6	56.3	85.2	71.0	77.5	63.0		
4	105.2	70.7	**81.7**	68.7	76.8	62.5	102.6	56.2	84.9	70.6	77.6	62.8		
5	105.3	728	75.0	70.5	77.3	62.7	102.9	56.9	74.3	81.3	76.7	62.2		
6	104.9	73.0	75.0	70.6	77.2	62.6	102.8	56.9	74.4	80.7	74.7	**67.7**		
7	105.7	72.5	74.7	70.1	74.9	**68.1**	102.6	56.7	75.2	81.8	76.5	62.1		
8	105.0	71.1	**82.0**	68.7	77.0	62.6	103.0	56.8	74.4	81.4	76.7	62.1		

[a] The assignments of the chemical shifts are based on ^{1}H, ^{13}C, DEPT-90, DEPT-135, HMQC, HMBC, and 1D-selective TOCSY NMR experiments. The chemical shifts shown in bold and underlined denote the signals of sulfated carbon or proton atoms adjacent to the sulfate groups.

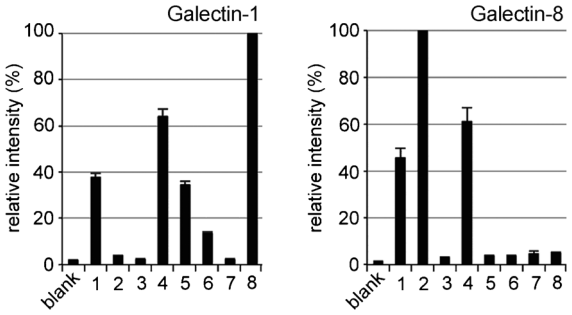


Figure 2. Relative binding specificities of compounds **1**–**8** with galectins-1 and -8. The results were averaged from at least three independent assays. A blank experiment was performed in the absence of the synthesized product.

and **5**, respectively; Figure 2). Moreover, galectins-1 and -8 exhibited dissimilar binding patterns towards disaccharides **1**–**8**. Specifically, galectin-8 preferentially bound to β1,3-linked disaccharides. Our results are consistent with previous reports,[25] including data that were released by the Consortium for Functional Genomics (CFG)[25b] and those obtained by using a flow cytometry study in which splenic B cells were stained with galectin-1-FITC or galectin-8-FITC and then treated with compounds **1**–**8**.[24a]

Conclusions

Herein, we have presented an efficient procedure for the preparation of protected Gal-β1,3/4-GlcNAc disaccharides. Both saccharide precursors were used to systematically introduce sulfate groups at specific positions and to rapidly construct longer glycans by modular assembly. This method could potentially be used for the synthesis of other sulfated oligosaccharides, such as keratan sulfate oligosaccharides, which are glycosaminoglycans and contain sulfated *N*-acetyllactosamine-repeating disaccharides. The method could also be applied to the preparation of uronic-acid-containing glycans if the C6-protecting group on Gal or GlcNAc can be selectively removed and oxidized. We are currently preparing other sulfated oligosaccharides and analogues for comparison of their galectin-binding specificities.

Experimental Section

General Considerations

All of the reactions were performed under a nitrogen atmosphere in oven-dried glassware unless otherwise indicated. The reaction products were purified by using column chromatography on silica gel.[26] Anhydrous solvents and moisture-sensitive materials were transferred by using an oven-dried syringe or cannula through a rubber septum. Organic solutions were concentrated under reduced pressure in a water bath (< 40 °C). Analytical TLC was performed on pre-coated SiliaFlash P60 glass plates (230–400 mesh, 250 μm thick, Silicyle) and was detected by UV visualization (254 nm) and/or by staining with reagents that contained phosphomolybdic acid hydrate (for general use), *para*-anisaldehyde (for carbohydrates), or ninhydrin (for amino-group-containing samples). Column chromatography on silica gel was performed on SiliaFlash G60 (70–230 mesh) or SiliaFlash P60 (230–400 mesh) from Silicyle. Purification of the bulk building blocks were either performed on a Teledyne Isco CombiFlash R_f that was equipped with a UV detector (for compounds with UV-active chromophores) or on a Grace Davison Reveleris flash system that was equipped with an Evaporative Light Scattering Detector (ELSD, for compounds without UV-active chromophores). Gel-filtration chromatography (Sephadex LH-20, G-10 and G-25), ion-exchange chromatography (GE HiTrap Q HP Column), and spin desalting column chromatography (Thermo Zeba spin desalting column, 7K MWCO) were used to achieve satisfactory purities of the final disaccharide products. ^{1}H

and ^{13}C NMR spectra were recorded on Bruker AV-400 (400 MHz) or AVII-500 (500 MHz) spectrometers by using tetramethylsilane (δ_H = 0.00 ppm), $CDCl_3$ (δ_H = 7.26 ppm), or CD_3OD (δ_H = 3.31 ppm, central line of a quintet) as internal standards. ^{13}C NMR spectra were recorded on Bruker AV-400 (100 MHz) or AVII-500 (125 MHz) spectrometers by using $CDCl_3$ (δ_C = 77.2 ppm, central line of a triplet) or CD_3OD (δ_C = 49.2 ppm, central line of a septet) as internal standards. 2D NMR spectra (including ^1H-^1H COSY, ^1H-^{13}C HMQC, and NOESY) were acquired on Bruker AV-400 or AVII-500 spectrometers. High-resolution mass spectroscopy (HRMS) was performed on Bruker Bio-TOF III (ESI-TOF) or Bruker Ultraflex (MALDI-TOF/TOF) spectrometers and is reported as mass/charge (m/z) ratios with percentage relative abundance. Optical rotations were measured at the sodium D-line (589 nm) at 25 °C on a PerkinElmer Model 341 Polarimeter. Specific rotations were reported as $[\alpha]_D^{25}$ after dividing the observed values by the sample concentration (C, in g mL^{-1}) and the path length (l, in dm).

The solvents for extraction and chromatography were of ACS grade. CH_2Cl_2, MeCN, and THF were pre-dried by using molecular sieves and then percolated through an active Al_2O_3 column.[27] Anhydrous DMF and MeOH were purchased from Acros Co. in an AcroSeal package. Diphenylsulfoxide (Ph_2SO), 2,4,6-tri-*tert*-butylpyrimidine, and triethylphosphine (1.0 M in THF) were purchased from Aldrich Chemical Co. All of the chemicals were used without further purification unless otherwise specified. Celite 545 and 3 Å molecular sieves (powder < 50 μm) were purchased from Acros Co. 1,2,3,4,6-Penta-*O*-acetyl-β-D-galactopyranoside, D-glucosamine hydrochloride, and 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (EDC) were purchased from Carbosynth Ltd. in a bulk package. Tetra-*n*-butylammonium fluoride (TBAF, 1.0 M in THF) was purchased from Alfa Aesar.

General Procedure for Measuring the Binding Affinities between Synthetic Sulfated Sugars and Galectins-1 and -8

The binding affinity of the synthesized sugars to galectins-1 and -8 was measured by using a previously reported AlphaScreen-based solution carbohydrate array.[23] The measurements were performed on a PerkinElmer Envision instrument. The donor beads and acceptor beads were purchased from PerkinElmer Life Sciences, Inc. (Boston, MA, USA). Recombinant galectin-1 and galectin-8 were prepared according to a literature procedure.[24b]

*6-Azidohexyl (β-D-galactopyranosyl)-(1→3)-2-acetamido-2-deoxy-β-D-glucopyranoside (**1**)*

White amorphous solid in 54% overall yield (3 steps from compound **32**). R_f = 0.55 (IPA/H_2O/NH_4OH, 7:2:1 v/v/v); $[\alpha]_D^{25}$ = +1.1 (c = 0.3, MeOH); ^1H NMR (500 MHz, CD_3OD): δ = 4.47 (d, J = 8.0 Hz, 1H), 4.27 (d, J = 7.5 Hz, 1H), 3.91–3.88 (m, 2H), 3.80 (d, J = 2.7 Hz, 1H), 3.78–3.65 (m, 6H), 3.56–3.52 (m, 2H), 3.50–2.40 (m, 3H), 3.28 (t, J = 7.0 Hz, 2H; CH_2N_3), 1.96 (s, 3H; $COCH_3$), 1.59–1.57 (m, 4H; alkyl chain), 1.41–1.39 ppm (4H, m; alkyl chain); ^{13}C NMR (125 MHz, CD_3OD): δ = 174.3, 105.8, 102.5, 85.1, 77.7, 77.3, 74.8, 72.5, 70.7, 70.6, 70.4, 62.8, 62.7, 56.5, 52.5, 30.6, 30.1, 27.7, 26.8, 23.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{20}H_{36}N_4O_{11}Na$: 531.2273 $[M+Na]^+$; found: 531.2265.

*6-Azidohexyl (β-D-galactopyranosyl)-(1→3)-2-acetamido-2-deoxy-6-O-sulfonato-β-D-glucopyranoside Sodium Salt (**2**)*

White amorphous solid in 37% overall yield (4 steps from compound **32**). R_f = 0.70 (IPA/H_2O/NH_4OH, 7:2:1 v/v/v); $[\alpha]_D^{25}$ = −2.9 (c = 0.7, MeOH); ^1H NMR (500 MHz, CD_3OD): δ = 4.50 (d, J = 8.2 Hz, 1H), 4.43 (dd, J = 10.8, 1.9 Hz, 1H), 4.33 (d, J = 7.4 Hz, 1H), 4.13 (dd, J = 10.8, 6.3 Hz, 1H), 3.91–3.87 (m, 1H), 3.83–3.77 (m, 3H), 3.75–3.59 (m, 5H), 3.56–3.49 (m, 3H), 3.43 (dd, J = 9.7, 8.2 Hz, 1H), 3.30 (t, J = 6.7 Hz, 2H; CH_2N_3), 2.01 (s, 3H; $COCH_3$), 1.62–1.58 (m, 4H; alkyl chain), 1.42–1.40 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 174.5, 105.6, 102.4, 84.8, 77.2, 75.7, 74.8, 72.5, 70.8, 70.7, 70.5, 68.6, 62.7, 56.5, 52.5, 30.6, 30.0, 27.6, 26.8, 23.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{20}H_{35}N_4NaO_{14}SNa$: 633.1660 $[M+Na]^+$; found: 633.1655.

*6-Azidohexyl (6-O-sulfonato-β-D-galactopyranosyl)-(1→3)-2-acetamido-2-deoxy-β-D-glucopyranoside Sodium Salt (**3**)*

The following four paragraphs describe the detailed procedure for the synthesis of compound **3** from compound **33**. For the structures of these compounds, see the Supporting Information, Scheme 5.

To a solution of compound **33** (250 mg, 0.25 mmol) was added an 80% aqueous solution of HOAc (5 mL). The resulting mixture was heated at 50 °C for 2 h and then co-evaporated with toluene three times to give a white solid. The solid was dissolved in anhydrous pyridine (3 mL) at 0 °C under a nitrogen atmosphere and treated with Ac_2O (1 mL) and a catalytic amount of DMAP (5 mg). After removing the ice bath, the reaction mixture was stirred at RT for 4 h, diluted with EtOAc, washed with a 1 M aqueous solution of HCl (three times), a saturated aqueous solution of $NaHCO_3$, water, and brine, dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:1) to provide compound **35** (197 mg, 79% yield over two steps) as a white amorphous foam.

To a solution of compound **35** (150 mg, 0.15 mmol) in anhydrous THF (3 mL) were sequentially added HOAc (25.5 μL, 0.45 mmol) and TBAF (1.0 M in THF, 0.45 mL, 0.45 mmol) at 0 °C under a nitrogen atmosphere. The reaction mixture was gradually warmed to RT and stirred for 15 h. The reaction mixture was diluted with EtOAc and then washed with a saturated aqueous solution of $NaHCO_3$, water, and brine. The organic layer was dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure to give a dry residue that was purified by column chromatography on silica gel (EtOAc) to afford compound **36** (83.3 mg, 73% yield) as a white amorphous solid.

Compound **36** (70.0 mg, 90.3 μmol) was dissolved in anhydrous DMF (2 mL) and treated with sulfur trioxide trimethylamine complex (SO_3·TMA, 62.9 mg, 0.45 mmol) at RT under a nitrogen atmosphere. The reaction was heated at 50 °C for 3 h, stopped by the addition of MeOH at RT, and co-evaporated with toluene three times. The resulting residue was dissolved in MeOH (5 mL) and subjected to ion exchange [Na^+] on the IR-120 resin to generate the sodium salt. After the filtration, the filtrate was concentrated under reduced pressure and purified by column chromatography on silica gel (MeOH/$CHCl_3$, 1:5) to give compound **37** (63.4 mg, 80% yield) as a white amorphous foam.

Compound **37** (50 mg, 57.0 μmol) was dissolved in MeOH (2 mL) and treated with a catalytic amount of NaOMe (1 mg) at RT under a nitrogen atmosphere. After stirring for 2.5 h, the reaction was neutralized by the addition of Amberlite IR-120 [H^+] resin and then filtered. The filtrate was concentrated in vacuo and purified by column chromatography on silica gel (EtOAc/MeOH/H_2O, 8:2:1 with 1% Et_3N) to afford the product as a white foam. Further ion-exchange chromatography was performed on a GE HiTrap Q HP column (gradient elution with NH_4HCO_3) to give the final product (**3**, 29.6 mg, 85% yield) as white powder. R_f = 0.70 (IPA/H_2O/NH_4OH, 7:2:1 v/v/v); $[\alpha]_D^{25}$ = −2.4 (c = 1.3, MeOH); ^1H NMR (500 MHz, CD_3OD): δ = 4.46 (d, J = 8.4 Hz, 1H), 4.32 (d, J = 7.3 Hz, 1H), 4.18 (d, J = 6.2 Hz, 1H), 4.91–4.85 (m, 4H), 3.79–3.67 (m, 3H), 3.57–3.47 (m, 3H), 3.40 (t, J = 9.5 Hz, 1H), 3.35–3.32 (m, 1H), 3.28 (t, J = 6.9 Hz, CH_2N_3, 2H), 1.98 (s, 3H; $COCH_3$), 1.60–1.57 (m, 4H; alkyl chain), 1.40–1.38 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, CD_3OD): δ = 174.3 (C=O), 105.7 (CH), 102.6 (CH), 85.2 (CH), 77.5(CH), 74.8 (CH), 74.5 (CH), 72.3 (CH), 71.0 (CH), 70.6 (CH_2), 70.0 (CH), 67.9 (CH_2), 63.0 (CH_2), 56.3 (CH), 52.5 (CH_2), 30.6 (CH_2), 30.0 (CH_2), 27.6 (CH_2), 26.8 (CH_2), 23.4 ppm (CH_3); HRMS (ESI-TOF): m/z calcd for $C_{20}H_{35}N_4NaO_{14}SNa$: 633.1660 $[M+Na]^+$; found: 633.1678.

*6-Azidohexyl (3-O-sulfonato-β-D-galactopyranosyl)-(1→3)-2-acetamido-2-deoxy-β-D-glucopyranoside Sodium Salt (**4**)*

White amorphous solid in 26% overall yield (6 steps from compound **32**). R_f = 0.70 (IPA/H_2O/NH_4OH, 7:2:1 v/v/v); $[\alpha]_D^{25}$ = −33 (c = 0.1, MeOH); ^1H NMR (500 MHz, CD_3OD): δ = 4.70 (t, J = 4.0 Hz, 1H), 4.40 (dd, J = 10.0, 7.5 Hz, 1H), 4.30 (t, J = 9.6 Hz, 1H), 3.96 (d, J = 8.2 Hz, 1H), 3.94 (d, J = 7.5 Hz, 1H), 3.91 (dd, J = 10.0, 4.0 Hz, 1H), 3.85 (dd, J = 10.0, 8.0 Hz, 1H), 3.84–3.82 (m, 3H), 3.82–3.80 (m, 1H), 3.79 (dd, J = 9.0, 8.2 Hz, 1H), 3.77–3.75 (m, 1H), 3.70 (t, J = 6.5 Hz, 2H), 3.58 (m, 1H),

3.34 (t, $J=7.1$ Hz, 1H), 3.32 (t, $J=7.1$ Hz, 1H), 2.04 (s, 3H; $COCH_3$), 1.63 (m, 4H; alkyl chain), 1.45 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, CD_3OD): $\delta=172.8$, 103.7, 101.1, 83.4, 80.1, 76.0, 75.3, 69.2, 69.1, 67.1, 61.3, 61.0, 54.7, 51.0, 47.9, 47.8, 47.6, 47.5, 47.3, 47.1, 29.0, 28.5, 26.1, 25.2, 21.8 ppm; HRMS (MALDI-TOF): m/z calcd for $C_{20}H_{35}N_4NaO_{14}SNa$: 633.1660 $[M+Na]^+$; found: 633.1619.

*6-Azidohexyl (β-D-galactopyranosyl)-(1→4)-2-acetamido-2-deoxy-β-D-glucopyranoside (**5**)*

White amorphous solid in 67% overall yield (2 steps from compound **33**). $R_f=0.60$ (IPA/H_2O/NH_4OH=7:2:1 v/v/v); $[\alpha]_D^{25}=-3.0$ ($c=0.7$, MeOH); ^1H NMR (500 MHz, CD_3OD): $\delta=4.40$ (d, $J=8.4$ Hz, 1H), 4.38 (d, $J=8.1$ Hz, 1H), 3.92–3.86 (m, 3H), 3.81 (d, $J=2.4$ Hz, 1H), 3.78–3.64 (m, 4H), 3.62–3.52 (m,4H), 3.45–3.44 (m, 2H), 3.40–3.38 (m, 1H), 3.28 (t, $J=6.9$ Hz, 2H; CH_2N_3), 1.97 (s, 3H; $COCH_3$), 1.59–1.56 (m, 4H; alkyl chain), 1.39–1.38 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, CD_3OD): $\delta=173.6$, 105.3, 102.9, 81.2, 77.3, 76.7, 75.0, 74.4, 72.8, 70.6, 70.5, 62.7, 62.1, 56.9, 52.6, 30.6, 30.1, 27.2, 28.8, 23.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{20}H_{36}N_4O_{11}Na$: 531.2273 $[M+Na]^+$; found: 531.2280.

*6-Azidohexyl (β-D-galactopyranosyl)-(1→4)-2-acetamido-2-deoxy-6-O-sulfonato-β-D-glucopyranoside Sodium Salt (**6**)*

White amorphous solid in 34% overall yield (3 steps from compound **33**). $R_f=0.70$ (IPA/H_2O/NH_4OH, 7:2:1 v/v/v); $[\alpha]_D^{25}=-1.2$ ($c=0.4$, MeOH); ^1H NMR (500 MHz, CD_3OD): $\delta=4.51$ (d, $J=7.5$ Hz, 1H), 4.43 (d, $J=8.3$ Hz, 1H), 4.37–4.30 (m, 2H), 3.88–3.83 (m, 2H), 3.79–3.61 (m, 8H), 3.54–3.46 (m, 3H), 3.28 (t, $J=6.8$ Hz, 2H; CH_2N_3), 2.01 (s, 3H; $COCH_3$), 1.60–1.55 (m, 4H; alkyl chain), 1.40–1.38 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta=174.1$, 104.8, 102.6, 80.6, 77.2, 74.9, 74.7, 74.3, 72.9, 70.7, 70.6, 67.6, 62.7, 57.0, 52.5, 30.6, 30.0, 27.6, 26.7, 22.9 ppm; HRMS (ESI-TOF): m/z calcd for $C_{20}H_{35}N_4NaO_{14}SNa$: 633.1660 $[M+Na]^+$; found: 633.1669.

*6-Azidohexyl (6-O-sulfonato-β-D-galactopyranosyl)-(1→4)-2-acetamido-2-deoxy-β-D-glucopyranoside Sodium Salt (**7**)*

White amorphous solid in 55% overall yield (3 steps from compound **33**). (IPA/H_2O/NH_4OH=7/2/1 v/v/v) $R_f=0.70$; $[\alpha]_D^{25}=-1.3$ ($c=0.9$, MeOH); ^1H NMR (500 MHz, CD_3OD): $\delta=4.44$ (d, $J=8.4$ Hz, 1H; H1), 4.40 (d, $J=7.2$ Hz, 1H; H1′), 4.20 (dd, $J=11.0$, 7.7 Hz, 1H; H6a′) 4.16 (dd, $J=11.0$, 5.0 Hz, 1H; H6b′), 3.93–3.86 (m, H4′, H6ab, 4H; OCH_2), 3.77–3.71 (m, 1H; H2), 3.64–3.60 (m, 2H; H3, H4), 3.57–3.53 (m, 2H; H3′, H2′), 3.50 (dt, $J=9.7$, 6.6 Hz, 1H; OCH_2), 3.44–3.42 (m, 1H; H5), 3.28 (t, $J=6.9$ Hz, 2H; CH_2N_3), 1.99 (s, 3H; $NCOCH_3$), 1.60–1.56 (m, 4H; alkyl chain), 1.40–1.36 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta=174.2$ (C=O), 105.3 (CH), 102.6 (CH), 81.8 (CH), 76.4 (CH), 75.2 (CH), 74.9 (CH), 74.7 (CH), 72.5 (CH), 70.7 (CH_2), 70.1 (CH), 68.1 (CH_2), 62.1 (CH_2), 56.7 (CH), 52.5 (CH_2), 30.6 (CH_2), 30.0 (CH_2), 27.7 (CH_2), 26.8 (CH_2), 23.2 ppm (CH_3); HRMS (ESI-TOF): m/z calcd for $C_{20}H_{35}N_4NaO_{14}SNa$ $[M+Na]^+$ 633.1660; found: 633.1679.

*6-Azidohexyl (3-O-sulfonato-β-D-galactopyranosyl)-(1→4)-2-acetamido-2-deoxy-β-D-glucopyranoside Sodium Salt (**8**)*

White amorphous solid in 34% overall yield (4 steps from compound **33**). $R_f=0.20$ (EtOAc/MeOH/H_2O, 8:2:1 v/v/v); $[\alpha]_D^{25}=-36$ ($c=1.0$, MeOH); ^1H NMR (500 MHz, CD_3OD): $\delta=4.49$ (d, $J=7.8$ Hz, 1H; H1′), 4.39 (d, $J=8.4$ Hz, 1H; H1), 4.24 (dd, $J=9.7$, 3.2 Hz, 1H; H3′), 4.22 (d, $J=3.1$ Hz, 1H; H4′), 3.92 (dd, $J=12.1$, 2.6 Hz, 1H; H6a), 3.91–3.85 (m, 2H; H6b, OCH_2), 3.76 (dd, $J=11.6$, 7.6 Hz, 1H; H6a′), 3.73–3.67 (m, 3H; H2, H2′, H6b′), 3.65–3.59 (m, 3H; H3, H5′, H4), 3.47 (dt, $J=9.7$, 6.6 Hz, 1H; OCH_2), 3.40–3.38 (m, 1H; H5), 3.28 (t, $J=6.9$ Hz, 2H; CH_2N_3), 1.97 (s, 3H; $NCOCH_3$), 1.60–1.53 (m, 4H), 1.42–1.38 ppm (m, 4H); ^{13}C NMR (125 MHz, CD_3OD): $\delta=173.6$ (C=O), 105.0 (CH), 103.0 (CH), 82.0 (CH), 81.4 (CH), 77.0 (CH), 76.7 (CH), 74.4 (CH), 71.1 (CH), 70.6 (CH_2), 68.7 (CH), 62.6 (CH_2), 62.1 (CH_2), 56.8 (CH), 52.6 (CH_2), 30.6 (CH_2), 30.0 (CH_2), 27.7 (CH_2), 26.8 (CH_2), 23.1 ppm (CH_3); HRMS (ESI-TOF): m/z calcd for $C_{20}H_{35}N_4NaO_{14}SNa$: 633.1660 $[M+Na]^+$; found: 633.1619.

*4-Methylphenyl 2,3,4,6-tetra-O-acetyl-1-thio-β-D-galactopyranoside (**9**)[28]*

To a solution of 1,2,3,4,6-penta-*O*-acetyl-β-D-galactopyranoside (50.0 g, 128 mmol) and *para*-toluenethiol (19.3 g, 154 mmol) in anhydrous CH_2Cl_2 (300 mL) at 0°C under a nitrogen atmosphere was added dropwise $BF_3{\cdot}OEt_2$ (32.6 mL, 256 mmol). The reaction mixture was gradually warmed to RT and stirred for 16 h. The color of the solution changed to red when the reaction was complete. The reaction was quenched by the portion-wise addition of a saturated aqueous solution of $NaHCO_3$ at 0°C with vigorous stirring, washed with water and brine (three times each), and dried over $MgSO_4$. The filtrate was evaporated under reduced pressure to give a dry residue, which was purified by recrystallization from hot EtOH to give the desired product (**9**, 43.3 g, 86% yield) as a white solid. $R_f=0.50$ (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25}=+0.6$ ($c=1.3$, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$): $\delta=7.41$ (d, $J=8.1$ Hz, 2H; ArH), 7.13 (d, $J=8.1$ Hz, 2H; ArH), 5.40 (d, $J=3.3$ Hz, 1H; H4), 5.21 (t, $J=10.0$ Hz, 1H; H2), 5.04 (dd, $J=9.9$, 3.4 Hz, 1H; H3), 4.65 (d, $J=10.0$ Hz, 1H; H1), 4.18 (dd, $J=11.3$, 6.9 Hz, 1H; H6a), 4.11 (dd, $J=11.4$, 6.4 Hz, 1H; H6b), 3.91 (t, $J=6.6$ Hz, 1H; H5), 2.35 (s, 3H; $PhCH_3$), 2.11 (s, 3H; $COCH_3$), 2.10 (s, 3H; $COCH_3$), 2.04 (s, 3H; $COCH_3$), 1.97 ppm (s, 3H; $COCH_3$); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta=170.4$, 170.2, 170.1, 169.4, 138.5, 133.2, 129.6, 128.6, 87.0, 74.4, 72.1, 67.3, 67.3, 61.6, 21.1, 20.8, 20.65, 20.60, 20.56 ppm; HRMS (ESI-TOF): m/z calcd for $C_{21}H_{26}O_9SNa$: 477.1190 $[M+Na]^+$; found: 477.1199.

*4-Methylphenyl 6-O-tert-butyldiphenylsilyl-1-thio-β-D-galactopyranoside (**10**)[29]*

For details of the reactions, see the Supporting Information, Scheme 1.

To a solution of thiogalactoside **9** (10.0 g, 22.0 mmol) in anhydrous MeOH/CH_2Cl_2 (1:1, 200 mL) was added a catalytic amount of NaOMe (120 mg, 10 mol% yield). The reaction mixture was stirred at RT for 1 h under a nitrogen atmosphere. Amberlite IR-120 [H^+] resin was added to quench the reaction and to adjust the pH value to 6. The resulting mixture was filtered, concentrated, and co-evaporated with toluene three times. The resulting white solid was dissolved in anhydrous DMF (200 mL) and imidazole (3.00 g, 44.0 mmol) at 0°C, followed by the addition of TBDPSCl (6.9 mL, 26.4 mmol). The mixture was stirred at RT for a further 2.5 h under a nitrogen atmosphere. The reaction was quenched by the addition of MeOH (10 mL). After stirring at RT for 10 min, the solvent was removed under reduced pressure to give a dry residue that was purified by column chromatography (EtOAc/hexanes=2:1 v/v) to give compound **10** as a white solid (10.6 g, 92% yield). $R_f=0.50$ (EtOAc/hexanes, 2:1 v/v); $[\alpha]_D^{25}=-14$ ($c=1.0$, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): $\delta=7.72$ (d, $J=6.8$ Hz, 2H; ArH), 7.69 (d, $J=6.6$ Hz, 2H; ArH), 7.45–7.37 (m, 8H; ArH), 7.06 (d, $J=7.9$ Hz, 2H; ArH), 4.43 (d, $J=9.1$ Hz, 1H; H1), 4.13–3.99 (m, 1H; H4), 3.96–3.94 (m, 2H; H6a,b), 3.64–3.54 (m, 3H; H2, H3, H5), 2.81 (br, 1H; OH), 2.64 (d, $J=5.5$ Hz, 1H; OH), 2.47 (br, 1H; OH), 2.32 (s, 3H; $PhCH_3$), 1.07 ppm (s, 9H; *t*Bu); ^{13}C NMR ($CDCl_3$, 100 MHz): $\delta=138.2$, 135.7, 135.6, 133.0, 132.9, 132.7, 129.9, 129.8, 128.3, 127.8, 88.8, 78.1, 74.9, 69.9, 69.4, 63.8, 26.8, 21.1, 19.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{29}H_{36}O_5SSiNa$: 547.1945 $[M+Na]^+$; found: 547.1930.

*4-Methylphenyl 2,4-di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranoside (**12**)*

To a solution of 2,3,4-triol **10** (5.0 g, 9.53 mmol) and a catalytic amount of CSA (221 mg, 0.95 mmol) in MeCN (100 mL) at RT under a nitrogen atmosphere was added trimethyl orthoacetate (3.7 mL, 28.6 mmol). After stirring for 30 min, Et_3N was added to quench the reaction and the reaction mixture was dried under reduced pressure. After dissolving in CH_2Cl_2 (100 mL), to the resulting solution (which contained the O3,O4-orthoformate product) were sequentially added Et_3N (4.0 mL, 28.6 mmol), acetic anhydride (1.8 mL, 19.1 mmol), and DMAP (116 mg, 0.95 mmol). After stirring for 30 min, the solvent was removed under reduced pressure to give a dry residue and then poured into an 80% aqueous solution of AcOH (100 mL) with vigorous stirring for 30 min. The solvent was removed by evaporation and the residue was extracted with EtOAc. The collected organic layer was washed with an ice-cold saturated solution of aqueous $NaHCO_3$, water, and brine, and dried over

$MgSO_4$. The filtrate was evaporated under reduced pressure. To a solution that contained the resulting product (compound **11**) in anhydrous CH_2Cl_2 (100 mL) and levulinic acid (1.66 g, 14.3 mmol) were added EDC (2.74 g, 14.3 mmol) and 4-dimethylaminopyridine (DMAP, 116 mg, 0.95 mmol) at 0 °C under a nitrogen atmosphere. The ice bath was removed after the addition had been completed and the mixture was stirred at RT for 1 h, evaporated, redissolved in EtOAc, washed with a saturated aqueous solution of $NaHCO_3$, water, and brine and dried over anhydrous $MgSO_4$. The filtrate was concentrated under reduced pressure to give a dry residue that was purified by flash column chromatography (EtOAc/hexanes, 1:2 v/v) to afford compound **12** (5.25 g, 78% yield) as a white amorphous foam. R_f = 0.45 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25} = +1.6$ (c = 2.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.63–7.60 (m, 4H; ArH), 7.59–7.35 (m, 8H; ArH), 7.06 (d, J = 7.8 Hz, 2H; ArH), 5.51 (d, J = 2.3 Hz, 1H; H4), 5.18 (t, J = 9.9 Hz, 1H; H2), 5.06 (dd, J = 9.9, 2.4 Hz, 1H; H3), 4.64 (d, J = 9.9 Hz, 1H; H1), 3.78–3.77 (m, 2H; H5, H6a), 3.68–3.63 (m, 1H; H6b), 2.79–2.73 (m, 1H; Lev-CH_2), 2.63–2.51 (m, 2H; Lev-CH_2), 2.41–2.37 (m, 1H; Lev-CH_2), 2.31 (s, 3H; $PhCH_3$), 2.15 (s, 3H; $COCH_3$), 2.12 (s, 3H; $COCH_3$), 1.99 (s, 3H; $COCH_3$), 1.02 ppm (s, 9H; tBu); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 206.2, 171.6, 171.1, 170.1, 169.7, 138.1, 135.6, 132.9, 132.8, 132.7, 129.8, 129.7, 129.6, 129.1, 127.9, 127.8, 127.5, 87.2, 72.6, 67.4, 67.3, 61.5, 60.4, 51.8, 37.9, 37.6, 36.6, 29.8, 29.6, 27.8, 26.7, 24.7, 21.1, 21.0, 20.8, 20.6, 19.0, 14.7 ppm; HRMS (ESI-TOF): m/z calcd for $C_{38}H_{46}O_9SSiNa$: 729.2524 $[M+Na]^+$; found: 729.2529.

*2-Azido-4,6-O-benzylidene-2-deoxy-αβ-D-glucopyranoside (**13**)[17]*

For details of the reactions, see the Supporting Information, Scheme 2.

In situ preparation of TfN_3: To a vigorously stirring solution of sodium azide (NaN_3, 98 g, 1.50 mol) in H_2O/CH_2Cl_2 (1:1, 300 mL) was dropwise added trifluoromethanesulfonic anhydride (Tf_2O, 50 mL, 0.30 mol) at 0 °C over a period of 30 min. The resulting mixture turned into white cloudy solution and was stirred at 0 °C for a further 1.5 h. The organic layer was washed with water and a saturated aqueous solution of Na_2CO_3 was added until the pH value of the aqueous layer was above 7. The resulting solution of TfN_3 (in about 250 mL of CH_2Cl_2) was directly used in the next step without further purification.

Cu^{II}-catalyzed diazo transfer: The freshly prepared solution of TfN_3 (in CH_2Cl_2) was added to a solution of D-glucosamine hydrochloride (33 g, 0.15 mol), potassium carbonate (25 g, 0.18 mol), and a catalytic amount of $CuSO_4 \cdot 5H_2O$ (0.38 g, 1 mol% yield) in water (100 mL) at 0 °C. Then, the ice bath was removed and MeOH (400 mL) was added to make the reaction homogeneous. After vigorous stirring at RT for 18 h, the mixture was passed through a pad of Celite and the filtrate was concentrated under reduced pressure to give a dry residue that was purified by column chromatography on silica gel (acetone) to give the azide product.

4,6-Benzylidene protection: Benzaldehyde dimethyl acetal (46.1 mL, 0.31 mol) was added to a solution of the aforementioned azide product (33 g, 0.11 mol) and a catalytic amount of camphorsulfonic acid (CSA, 8.89 g, 38.3 mmol) in anhydrous MeCN (300 mL) at RT under a nitrogen atmosphere. After stirring at RT for 5 h, the reaction was quenched by the addition of Et_3N, concentrated in vacuo, redissolved in EtOAc, sequentially washed with a saturated aqueous solution of $NaHCO_3$, water, and brine, and dried over $MgSO_4$. The filtrate was concentrated under reduced pressure to give a dry residue that was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2). The desired fractions were concentrated in vacuo to afford a yellowish foam that was solidified from $CHCl_3$/Et_2O/hexanes (1:5:20, v/v/v) to obtain compound **13** (28.7 g) as white powder (as a mixture of α/β-anomers, 1:1.7) in 64% yield (of the last two steps). R_f = 0.39 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25} = -87$ (c = 1.3, MeOH); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.50–7.47 (m, 5.4H ($\alpha+\beta$); ArH), 7.41–7.37 (m, 7.1H ($\alpha+\beta$); ArH), 5.549 (s, 1H (α); PhCH), 5.545 (s, 1.7H (β); PhCH), 5.32 (t, J = 3.1 Hz, 1H (α); H1), 4.72 (dd, J = 7.7, 4.6 Hz, 1.7H (β); H1), 4.33 (dd, J = 10.3, 5.1 Hz, 1.7H (β); H6a), 4.28 (dd, J = 10.3, 5.0 Hz, 1H (α); H6a), 4.24 (dd, J = 9.5, 1.7 Hz, 1H (α); H4), 4.10 (ddd, J = 15.0, 5.0, 5.0 Hz, 1H (α); H5), 3.78 (t, J = 10.3 Hz, 1.7H (β); H6b), 3.73 (t, J = 10.3 Hz, 1H (α); H6b), 3.70 (dd, J = 9.4, 2.0 Hz, 1.7H (β); H4), 3.59 (t, J = 9.4 Hz, 1.7H (β); H3), 3.54 (t, J = 9.5 Hz, 1H (α); H3), 3.45 (ddd, J = 14.5, 5.0, 4.9 Hz, 1.7H (β); H5), 3.39 (dd, J = 9.5, 3.1 Hz, 1.7H (α); H2), 3.37 (dd, J = 9.5, 7.7 Hz, 1.7H (β); H2), 3.03 (d, J = 2.6 Hz, 1H (α); OH), 2.78 (d, J = 2.3 Hz, 1H (α); OH), 2.76 ppm (d, J = 2.3 Hz, 1.7H (β); OH); HRMS (ESI-TOF): m/z calcd for $C_{13}H_{15}N_3O_5Na$: 316.0904 $[M+Na]^+$; found: 316.0915.

*(2,4-Di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-azido-4,6-O-benzylidene-2-deoxy-αβ-D-glucopyranoside (**17**)*

A solution of thiogalactoside **12** (200 mg, 0.28 mmol) in anhydrous CH_2Cl_2/toluene (2:1, 9 mL) was mixed with 2,4,6-tri-*tert*-butylpyrimidine (TTBP, 73.0 mg, 0.29 mmol) and diphenylsulfoxide (Ph_2SO, 62 mg, 0.31 mmol). The reaction mixture was stirred in the presence of 3 Å molecular sieves (400 mg, freshly dried prior to use) at RT for 30 min under a nitrogen atmosphere and subjected to the addition of Tf_2O (51 μL, 0.31 mmol) after cooling to −60 °C. Upon consumption of the glycosyl donor (by TLC, 10 min), a solution of glycosyl acceptor **13** (123 mg, 0.42 mmol) in anhydrous CH_2Cl_2/MeCN (2:1, 9 mL) was added to the reaction mixture. After stirring at −60 °C for a further 1 h, the reaction was stopped with the addition of Et_3N and filtered through a pad of Celite. The filtrate was concentrated in vacuo to give a crude residue, which was purified by flash column chromatography (EtOAc/hexanes, 1:2) to give compound **17** (213 mg, 86% yield) as an amorphous foam (H1-anomeric isomers, H1α/H1β 1:1.1). R_f = 0.37 (EtOAc/hexanes = 1:1 v/v); $[\alpha]_D^{25} = -18$ (c = 0.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.54 (d, J = 7.3 Hz, 4.2H; ArH($\alpha+\beta$)), 7.50 (d, J = 7.3 Hz, 4.2H; ArH($\alpha+\beta$)), 7.42–7.33 (m, 16.8H; ArH($\alpha+\beta$)), 7.18–7.13 (m, 2.1H; ArH($\alpha+\beta$)), 7.10–7.06 (m, 4.2H; ArH($\alpha+\beta$)), 5.55 (s, 2.1H; H4′($\alpha+\beta$)), 5.46 (s, 2.1H; PhCH($\alpha+\beta$)), 5.31 (br, 1H; H1(α)), 5.23 (t, J = 8.6 Hz, 2.1H; H2′($\alpha+\beta$)), 5.06 (d, J = 10.6 Hz, 2.1H; H3′($\alpha+\beta$)), 4.77 (d, J = 8.6 Hz, 1H; H1′(α)), 4.75 (d, J = 8.6 Hz, 1.1H; H1′(β)), 4.69 (t, J = 6.7 Hz, 1.1H; H1(β)), 4.27 (dd, J = 10.0, 4.3 Hz, 1.1H; H6a(β)), 4.22 (dd, J = 10.0, 3.8 Hz, 1H; H6a(α)), 4.15 (t, J = 10.0 Hz, 1H; H3(α)), 4.09–4.01 (m, 1H; H5(α)), 3.75–3.71 (m, 2.1H; H5′($\alpha+\beta$)) 3.73 (t, J = Hz, 1.1H; H6b(β)), 3.68 (t, J = 10.0 Hz, 1H; H6b(α)), 3.66–3.59 (m, 4.3H; H3(β), H4(β), H6ab′($\alpha+\beta$)), 3.62 (t, J = 9.9 Hz, 1H; H4(α)), 3.51 (br, 1.1H; OH(β)), 3.38–3.31 (m, 3.2H; H5(β), H2(β), H2(α)), 2.99 (br, 1H; OH(α)), 2.80–2.75 (m, 2.1H; Lev-CH_2 ($\alpha+\beta$)) 2.65–2.52 (m, 4.2H; Lev-CH_2($\alpha+\beta$)), 2.42–2.39 (m, 2.1H; Lev-CH_2($\alpha+\beta$)), 2.16 (s, 6.3H; $COCH_3$($\alpha+\beta$)), 2.13 (s, 6.3H; $COCH_3$($\alpha+\beta$)), 1.94 (s, 3H; $COCH_3$(α)), 1.93 (s, 3.3H; $COCH_3$(β)), 0.98 ppm (s, 18.9H; tBu($\alpha+\beta$)); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 206.67, 206.63, 206.61, 172.0, 170.4, 170.23, 170,21, 170.14, 137.13, 137.06, 135.97, 135.95, 135.76, 133.03, 133.01, 132.8, 130.09, 130.02, 129.2, 128.3, 128.0, 125.91, 125.86, 101.76, 101.72, 101.3, 101.1, 97.1, 93.1, 80.4, 79.7, 79.3, 77.4, 77.25, 77.23, 73.2, 73.1, 71.9, 71.8, 69.70, 69.66, 68.9, 68.5, 67.7, 66.91, 66.87, 66.7, 63.8, 62.9, 60.6, 60.5, 37.9, 29.9, 28.1, 26.9, 21.0, 20.8, 19.11, 19.08 ppm; HRMS (ESI-TOF): m/z calcd for $C_{44}H_{53}N_3O_{14}SiNa$: 898.3189 $[M+Na]^+$; found: 898.3194.

*Acetyl (2,4,-Di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-azido-4,6-O-benzylidene-2-deoxy-β-D-glucopyranoside (**18**)*

The following glycosylation reaction was performed immediately after the sequential preparation of compound **12** without purification.

A solution of crude thiogalactoside **12** (which was obtained from a 4-step, consecutive procedure without purification; for details, see Scheme 2; 500 mg, 0.95 mmol of compound **10** were used at the start of the synthesis) in anhydrous CH_2Cl_2/toluene (2:1, 30 mL) was mixed with 2,4,6-tri-*tert*-butylpyrimidine (TTBP, 199 mg, 0.80 mmol) and diphenylsulfoxide (Ph_2SO, 170 mg, 0.84 mmol). The reaction mixture was stirred in the presence of 3 Å molecular sieves (freshly dried prior to use, 1.0 g) at RT for 30 min under a nitrogen atmosphere and subjected to the addition of Tf_2O (139 μL, 0.84 mmol) after cooling to −60 °C. Upon consumption of the glycosyl donor (by TLC, 10 min), a solution of glycosyl acceptor **13** (334 mg, 1.14 mmol) in anhydrous CH_2Cl_2/MeCN (2:1, 30 mL) was added to the reaction mixture. After stirring at −60 °C for a further 1 h, the reaction was stopped by the addition of Et_3N and filtered through a pad of Celite. The filtrate was concentrated in vacuo to give a dry residue that was redissolved in anhydrous CH_2Cl_2 (3.0 mL), Et_3N (0.64 mL,

4.56 mmol) and Ac_2O (0.21 mL, 2.28 mmol) were added, and the solution was stirred at 4 °C under a nitrogen atmosphere. After stirring at 4 °C for 18 h, the acetylation reaction was stopped by the addition of MeOH, evaporated in vacuo, redissolved in EtOAc, washed with a saturated aqueous solution of $NaHCO_3$ and brine, and dried over $MgSO_4$. The filtrate was concentrated and purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to give compound **18** (419 mg, 48% overall yield in 6 steps from compound **10**) as a white amorphous foam.

Preactivation method: A solution of thiogalactoside **12** (200 mg, 0.28 mmol) in anhydrous CH_2Cl_2/toluene (2:1, 9 mL) was mixed with 2,4,6-tri-*tert*-butylpyrimidine (TTBP, 73.0 mg, 0.29 mmol) and diphenylsulfoxide (Ph_2SO, 62 mg, 0.31 mmol). The reaction mixture was stirred in the presence of 3 Å molecular sieves (freshly dried prior to use, 400 mg) at RT for 30 min under a nitrogen atmosphere and Tf_2O (51 μL, 0.31 mmol) was added after cooling the mixture to −60 °C. Upon consumption of the glycosyl donor (by TLC, 10 min), a solution of glycosyl acceptor **19** (141 mg, 0.42 mmol) in anhydrous CH_2Cl_2 (9 mL) was added to the reaction mixture. After stirring at −60 °C for a further 1 h, the reaction was stopped by the addition of Et_3N and filtered through a pad of Celite. The filtrate was concentrated in vacuo to give a dry residue that was purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to give compound **18** (145 mg, 56% yield) as a white amorphous foam.

The NIS/TfOH method: A suspension of purified thiogalactoside **12** (379 mg, 0.54 mmol), acceptor **19** (120 mg, 0.36 mmol), and freshly dried 3 Å molecular sieves (500 mg) in anhydrous CH_2Cl_2 (3.6 mL) was stirred at RT for 30 min and then cooled to 0 °C under a nitrogen atmosphere. NIS (161 mg, 0.72 mmol) and TfOH (3.2 μL, 36 μmol) were added to the reaction and the mixture was stirred at the same temperature for a further 0.5 h. The reaction was stopped by the addition of Et_3N and filtered through a pad of Celite. The filtrate was sequentially washed with a saturated aqueous solution of $NaHCO_3$, a saturated aqueous solution of $Na_2S_2O_3$, water, and brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to give compound **18** (230 mg, 70% yield) as a pale-yellow amorphous foam. R_f = 0.30 (EtOAc/hexanes, 2:3 v/v); $[\alpha]_D^{25} = -29$ (c = 1.6, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.53–7.51 (m, 2H; ArH), 7.49–7.48 (m, 2H; ArH), 7.42–7.37 (m, 2H; ArH), 7.32 (t, J = 7.4 Hz, 6H; ArH), 7.14 (t, J = 7.2 Hz, 1H; ArH), 7.04 (d, J = 7.2 Hz, 2H; ArH), 5.91 (d, J = 8.8 Hz, 1H; H1), 5.53 (t, J = 3.0 Hz, 1H; H4′), 5.51 (s, 1H; PhCH), 5.15 (dd, J = 10.0, 8.0 Hz, 1H; H2′), 5.05 (dd, J = 10.0, 3.0 Hz, 1H; H3′), 4.75 (d, J = 8.0 Hz, 1H; H1′), 4.26 (m, 2H; H6ab), 3.79–3.77 (m, 1H; H5′), 3.75 (dd, J = 10.0, 8.8 Hz, H2), 3.65 (dd, J = 10.0, 3.7 Hz, H3), 3.63 (t, J = 3.7 Hz, 1H; H4), 3.60–3.52 (m, 3H; H5, H6ab′), 2.77–2.71 (m, 1H; Lev-CH_2), 2.60–2.48 (m, 2H; Lev-CH_2), 2.39–2.33 (m, 1H; Lev-CH_2), 2.11 (s, 3H; $COCH_3$), 2.08 (s, 3H; $COCH_3$), 2.05 (s, 3H; $COCH_3$), 1.96 (s, 3H; $COCH_3$), 1.96 (s, 3H; $COCH_3$), 0.97 ppm (s, 9H; *t*Bu); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 206.4, 171.9, 170.3, 170.0, 169.9, 138.4, 136.9, 136.0, 135.8, 133.0, 132.8, 130.1, 130.0, 129.3, 128.3, 128.0, 125.9, 101.6, 101.2, 93.4, 79.5, 77.5, 77.2, 77.1, 73.3, 71.8, 69.8, 68.3, 67.3, 66.9, 65.2, 60.7, 37.9, 29.8, 28.1, 26.9, 21.1, 21.0, 20.8, 19.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{46}H_{55}N_3O_{15}SiNa$: 940.3295 $[M+Na]^+$; found: 940.3295.

*Acetyl 2-Azido-4,6-O-benzylidene-2-deoxy-β-D-glucopyranoside (**19**)[17,18]*

Compound **19** was synthesized by the regio- and stereoselective acetylation of compound **13** according to a literature procedure.

*6-Azidohexyl 4,6-O-benzylidene-2-deoxy-2-(2,2,2-trichloroethoxycarbonylamino)-β-D-glucopyranoside (**20**)*

R_f = 0.25 (EtOAc/hexanes, 1:2 v/v); $[\alpha]_D^{25} = -30$ (c = 1.0, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.48–7.45 (m, 2H; ArH), 7.38–7.33 (m, 3H; ArH), 5.50 (s, 1H; PhCH), 5.32 (d, J = 8.0 Hz, 1H; NH), 4.74–4.69 (m, 2H; OCH_2CCl_3), 4.57 (s, 1H; H1), 4.32–4.29 (m, 1H; H6a), 4.09 (s, 1H; H3), 3.85–3.81 (m, 1H; OCH_2), 3.77–3.72 (t, J = 8.0 Hz, 1H; H6b), 3.52 (t, J = 8.0 Hz, 1H; H4), 3.46–4.42 (m, 2H; OCH_2, H5), 3.34–3.35 (m, 1H; H2), 3.25 (t, J = 7.0 Hz, 2H; CH_2N_3), 3.16 (s, 1H; OH), 1.57 (m, 4H; alkyl chain), 1.35 ppm (m, 4H; alkyl chain); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 154.7, 137.2, 129.6, 128.6, 126.6, 102.1, 101.2, 95.7, 81.7, 77.5, 70.9, 70.3, 68.8, 66.3, 59.1, 51.6, 29.6, 28.9, 26.6, 25.7 ppm; HRMS (ESI-TOF): m/z calcd for $C_{22}H_{29}C_{l3}N_4O_7Na$: 589.0994 $[M+Na]^+$; found: 589.0958.

*5-(Methoxycarbonyl)pentyl 2-trichloroacetamido-4,6-O-benzylidene-2-deoxy-β-D-glucopyranoside (**21**)*

For details of the reactions, see the Supporting Information, Scheme 4.

To a solution of D-glucosamine hydrochloride (10.0 g, 47.3 mmol) in anhydrous MeOH (100 mL) were sequentially added NaOMe (9 mL, 30% w/w in MeOH, 47.3 mmol), Et_3N (7.8 mL, 56.8 mmol), and trichloroacetyl chloride (TCACl, 6.2 mL, 56.8 mmol) at 0 °C. The reaction mixture was warmed to RT and stirred for 12 h. The reaction mixture was filtered through a pad of Celite and the filtrate was concentrated under reduced pressure. The resulting yellowish residue was redissolved in anhydrous CH_2Cl_2 (100 mL) and DMAP (30 mg, 0.24 mmol), Et_3N (13.6 mL, 98.3 mmol), and Ac_2O (9.0 mL, 98.3 mmol) were added at 0 °C. After stirring for 3 h, the reaction was stopped by the addition of MeOH and subjected to extraction with EtOAc. The collected organic layer was washed with a saturated aqueous solution of $NaHCO_3$, dried over $MgSO_4$, filtered, concentrated in vacuo, and purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to afford the peracetylated product (15.4 g, 66% yield) as a white solid.

The peracetylated product (10.0 g, 20.3 mmol) was mixed with *para*-toluenethiol (5.0 g, 40.3 mmol) in anhydrous CH_2Cl_2 (100 mL) at 0 °C under a nitrogen atmosphere and subjected to the dropwise addition of $BF_3{\cdot}OEt_2$ (6.40 mL, 50.5 mmol). The reaction mixture was gradually warmed to RT and stirred for a further 48 h. The reaction was stopped by the portion-wise addition of a saturated aqueous solution of $NaHCO_3$ at 0 °C with vigorous stirring. The organic layer was washed with water and brine, dried with anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure to give a dry residue that was purified by recrystallization from hot EtOH to give the desired thioglycoside (7.0 g, 62% yield) as a white powder.

A suspension of the thioglycoside (1.0 g, 1.79 mmol), methyl 6-hydroxyhexanoate (395 mg, 370 μL, 2.70 mmol), and 3 Å molecular sieves (1.5 g, freshly dried prior to use) in anhydrous CH_2Cl_2 (10 mL) was stirred at RT for 30 min, cooled to 0 °C under a nitrogen atmosphere, and sequentially treated with NIS (800 mg, 3.58 mmol) and TfOH (16 μL, 89 μmol). The reaction mixture was stirred at 0 °C for a further 30 min, quenched by the addition of Et_3N, and filtered through a pad of Celite. The filtrate was sequentially washed with a saturated aqueous solution of $NaHCO_3$, a saturated aqueous solution of $Na_2S_2O_3$, water, and brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to give the linker-tethered product (1.10 g, quantitative yield) as a white solid.

The product (200 mg, 0.35 mmol) was dissolved in anhydrous MeOH (2 mL) and treated with a catalytic amount of NaOMe (about 6 mg) under a nitrogen atmosphere. After stirring for 1 h at RT, Amberlite IR-120 [H^+] resin was added to neutralize the mixture. The resulting mixture was filtered, concentrated in vacuo, and then dissolved in anhydrous MeCN (2 mL) for the next step of the protection reaction. A catalytic amount of CSA (40 mg, 0.17 mmol) and benzaldehyde dimethyl acetal (0.1 mL, 0.69 mmol) were added at 0 °C under a nitrogen atmosphere. The mixture was warmed to RT and stirred for 5 h. The reaction was stopped by the addition of Et_3N (about 0.5 mL), concentrated under reduced pressure, washed with water (3×5 mL), and extracted with Et_2O to afford compound **21** (170 mg, 90% yield) as a white powder. R_f = 0.25 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25} = -31$ (c = 1.2, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.50–7.40 (m, 2H; ArH), 7.39–7.27 (m, 2H; ArH), 7.03 (d, J = 7.1 Hz, 1H; NH), 5.55 (s, 1H; PhCH), 4.93 (d, J = 8.6 Hz, 1H; H1), 4.83 (t, J = 10.2 Hz, 1H; H3), 4.39–4.34 (m, 1H; H6a), 3.87 (td, J = 9.7, 6.2 Hz, 1H; alkyl chain), 3.79 (t, J = 9.7 Hz, 1H; H6b), 3.67 (s, 3H; CO_2CH_3), 3.58 (m, 4H; H2, H4, H5, alkyl chain), 2.31 (d, J = 3.2 Hz, 1H; C3-OH), 2.30 (t, J = 7.4 Hz, 2H; alkyl chain), 1.65–1.62 (m, 4H; alkyl chain), 1.41–1.28 ppm (m, 2H; alkyl chain); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 174.3, 162.4, 137.1, 129.56, 128.6, 126.5, 102.1,

100.2, 92.7, 81.9, 70.3, 69.8, 68.8, 66.4, 59.9, 51.7, 34.1, 29.3, 25.7, 24.8 ppm; HRMS (ESI-TOF): *m/z* calcd for $C_{22}H_{28}Cl_3NO_8Na$: 562.0787 $[M+Na]^+$; found: 562.0773.

*Acetyl 2-Azido-3,6-di-O-benzyl-2-deoxy-β-D-glucopyranoside (**22**)[8d]*

For details of the reactions, see the Supporting Information, Scheme 2.

Triethylamine (28.6 mL, 205 mmol) was added to a solution of compound **13** (20.0 g, 68.2 mmol) and acetic anhydride (7.1 mL, 75.0 mmol) in anhydrous CH_2Cl_2 (500 mL) at 0 °C under a nitrogen atmosphere. Then, the mixture was gradually warmed to RT and stirred overnight. The reaction was quenched by the addition of MeOH (20 mL), stirred for 10 min, concentrated under reduced pressure, redissolved in EtOAc, washed with a saturated aqueous solution of $NaHCO_3$ and brine, and dried over $MgSO_4$. The filtrate was evaporated in vacuo to give a dry residue, which was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to afford the O1-acetate (18.6 g, 82 % yield).

A mixture of the aforementioned O1-acetate (10.0 g, 29.8 mmol) and Ag_2O (13.8 g, 59.6 mmol) in anhydrous CH_2Cl_2 (150 mL) was treated with benzyl bromide (6.1 mL, 50.7 mmol) at 0 °C under a nitrogen atmosphere. The reaction was gradually warmed to RT and stirred for a further 2 days. The resulting mixture was filtered through a pad of Celite. The filtrate was concentrated in vacuo to give a dry residue that was purified by column chromatography on silica gel (EtOAc/hexanes, 1:3) to afford the benzyl ether (11.2 g, 88 % yield) as a white solid.

To a solution of the benzyl ether (6.0 g, 14.1 mmol) and triethylsilane (Et_3SiH, 13.5 mL, 84.6 mmol) in anhydrous CH_2Cl_2 (120 mL) at 0 °C were dropwise added trifluoroacetic anhydride (TFAA, 2.0 mL, 14.1 mmol) and trifluoroacetic acid (TFA, 5.4 mL, 70.5 mmol). After stirring at 0 °C for 2 h, the reaction mixture was poured into a saturated aqueous solution of $NaHCO_3$ and extracted twice with EtOAc. The combined organic layer was washed with brine and dried over $MgSO_4$. The filtrate was concentrated under reduced pressure to give a dry residue that was purified by column chromatography on silica gel (EtOAc/hexanes, 1:4) to give compound **20** (5.18 g, 86 % yield) as a colorless oil. R_f = 0.45 (EtOAc/hexanes, 1:3 v/v); $[\alpha]_D^{25} = -23$ (c = 2.1, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.41–7.26 (m, 10H; ArH), 5.47 (d, J = 8.5 Hz, 1H; H1), 4.90 (d, J = 11.0 Hz, 1H; PhCH), 4.82 (d, J = 11.0 Hz, 1H; PhCH), 4.60 (d, J = 12.0 Hz, 1H; PhCH), 4.51 (d, J = 12.0 Hz, 1H; PhCH), 3.78–3.73 (m, 2H), 3.68 (dd, J = 4.4, 10.2 Hz, 1H), 3.55–3.49 (m, 2H), 3.38 (t, J = 9.0 Hz, 1H), 2.64 (d, J = 2.6 Hz, 1H; OH), 2.16 ppm (s, 3H; $COCH_3$); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 169.0, 137.8, 137.4, 128.6, 128.5, 128.2, 128.1, 128.0, 127.9, 92.9, 82.5, 75.3, 74.5, 73.8, 71.8, 69.5, 64.5, 21.0 ppm; HRMS (ESI-TOF): *m/z* calcd for $C_{22}H_{25}N_3O_6Na$: 450.1636 $[M+Na]^+$; found: 450.1637.

*5-(Methoxycarbonyl)pentyl 2-trichloroacetamido-3,6-di-O-benzyl-2-deoxy-β-D-glucopyranoside (**23**)*

For details of the reactions, see the Supporting Information, Scheme 4.

To a solution of compound **21** (1.0 g, 1.93 mmol) in anhydrous DMF (20 mL) was added sodium hydride (60 % NaH in mineral oil, 0.14 g, 5.79 mmol) at 0 °C under a nitrogen atmosphere. The mixture was stirred for 10 min at 0 °C and then benzyl bromide (BnBr, 470 μL, 3.85 mmol) and a catalytic amount of tetra-*n*-butylammonium iodide (TBAI, 70 mg, 0.19 mmol) were added at 0 °C. The reaction was stirred for a further 30 min and quenched by the slow addition of water (50 mL). The mixture was extracted with EtOAc (3×50 mL), washed with water and brine, dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to afford the benzyl ether (850 mg, 73 % yield) as a white solid.

The benzyl ether (120 mg, 0.19 mmol) was dissolved in anhydrous CH_2Cl_2 (1 mL) and triethylsilane (0.18 mL, 1.14 mmol), TFAA (24.6 μL, 0.19 mmol), and TFA (70.7 μL, 0.95 mmol) were sequentially added at 0 °C under a nitrogen atmosphere. The reaction mixture was stirred at 0 °C for 5 h and then stopped by the addition of a saturated aqueous solution of $NaHCO_3$. The organic layer was washed with water and brine, dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to give compound **23** (92 mg, 76 % yield) as a white solid. R_f = 0.18 (EtOAc/hexanes, 1:2 v/v); $[\alpha]_D^{25} = -7.7$ (c = 1.7, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.37–7.27 (m, 10H; ArH), 6.96 (d, J = 7.8 Hz, 1H; NH), 4.88 (d, J = 8.3 Hz, 1H; H1), 4.78 (ABq, 2H; $PhCH_2$), 4.60 (ABq, 2H; $PhCH_2$), 4.03 (dd, J = 10.4, 8.3 Hz, 1H; H3), 3.87 (td, J = 9.4, 6.2 Hz, 1H; OCH_2), 3.77 (dd, J = 9.9, 7.3 Hz, 1H; H6a), 3.76 (dd, J = 9.9, 7.3 Hz, 1H; H6b), 3.71 (dd, J = 8.8, 2.0 Hz, 1H; H4), 3.66 (s, 3H; CO_2CH_3), 3.56–3.51 (m, 1H; H5), 3.27 (td, J = 9.4, 6.2 Hz, 1H; alkyl chain), 3.45 (dd, J = 9.8, 7.8 Hz, 1H; H2), 2.79 (d, J = 2.6 Hz, 1H; OH), 2.29 (t, J = 2.6 Hz, 2H; CH_2CO_2Me), 1.63–1.57 (m, 4H; alkyl chain), 1.37–1.63 ppm (m, 2H; alkyl chain); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 174.3, 162.0, 138.3, 137.8, 128.8, 128.7, 128.3, 128.8, 128.1, 128.0, 99.5, 92.8, 79.8, 74.9, 74.0, 73.9, 73.8, 70.8, 69.9, 58.7, 51.7, 34.1, 29.4, 25.7, 24.8 ppm; HRMS (ESI-TOF): *m/z* calcd for $C_{29}H_{36}Cl_3NO_8Na$: 656.1375 $[M+Na]^+$; found: 656.1409.

*6-Azidohexyl (2,4-di-O-acetyl-6-O-tert-butylphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→3)-4,6-O-benzylidene-2-deoxy2-(2,2,2-trichloroethoxycarbonylamino)-β-D-glucopyranoside (**24**)*

A suspension solution of thiogalactoside **12** (158 mg, 0.22 mmol), acceptor **20** (98 mg, 0.17 mmol), and 3 Å molecular sieves (550 mg, freshly dried prior to use) in anhydrous CH_2Cl_2 (6 mL) was stirred at RT for 30 min under a nitrogen atmosphere, cooled to 0 °C, and treated with NIS (100 mg, 0.45 mmol) and TfOH (1.5 μL, 17 μmol). The reaction mixture was stirred at 0 °C for 30 min, quenched by the addition of Et_3N, and filtered through a pad of Celite. The filtrate was sequentially washed with a saturated aqueous solution of $NaHCO_3$, a saturated aqueous solution of $Na_2S_2O_3$, water, and brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to give compound **24** (140 mg, 71 % yield) as a pale-yellow amorphous foam. R_f = 0.30 (EtOAc/hexanes, 1:2 v/v); $[\alpha]_D^{25} = -14$ (c = 1.1, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.63–7.3 (m, 12H; ArH), 7.09 (d, J = 7.0 Hz, 2H; ArH), 7.01 (m, 2H; ArH), 5.49 (d, J = 2.0 Hz, 1H; H4′), 5,41 (s, 1H; PhCH), 5.25 (s, 1H; NH), 5.17 (t, J = 10.0 Hz, 1H; H2′), 4.99 (dd, J = 10.0 Hz, 3.0 Hz, 1H; H3′), 4.80 (d, J = 11.0 Hz, 2H; H1, OCH_2CCl_3), 4.68 (m, 2H; H1′,OCH_2CCl_3), 4.32 (m, 1H; H3), 4.28(dd, J=11.0 Hz, 5.0 Hz, 1H; H6a), 3.83–3.80 (m, 1H; OCH_2), 3.74–3.66 (m, 2H; H5′, H6b), 3.60–3.50 (m, 3H; H4, H6a, H6b), 3.46–3.37 (m, 2H; H5, OCH_2), 3.24 (t, J = 7.0 Hz, 2H,CH_2N_3), 3.19 (d, J = 8.0 Hz, 1H; H2), 2.78–2.72 (m, 1H; Lev-CH_2), 2.60–2.48 (m, 2H; Lev-CH_2), 2.38–2.32 (m, 1H; Lev-CH_2), 2.12 (s, 3H; $COCH_3$), 2.06 (s, 3H; $COCH_3$), 1.88 (s, 3H; $COCH_3$), 1.55–1.54 (m, 4H; alkyl chain), 1.36–1.33 (m, 4H; alkyl chain), 0.95 ppm (s, 9H; *t*Bu); ^{13}NMR (125 MHz, $CDCl_3$): δ = 206.4, 171.8, 170.3, 169.9, 154.0, 137.2, 136.0, 135.8, 133.0, 132.7, 130.1, 130.0, 129.8, 129.1, 128.2, 128.0, 125.9, 101.4, 101.1, 100.4, 95.6, 80.1, 77.5, 73.0, 71.8, 70.3, 69.6, 68.7, 66.9, 66.3, 60.5, 58.6, 51.5, 37.8, 29.8, 29.5, 28.9, 28.0, 26.9, 26.6, 25.7, 21.0, 20.8, 19.0 ppm; HRMS (ESI-TOF): *m/z* calcd for $C_{53}H_{67}C_{l3}N_4O_{16}SiNa$: 1171.3285 $[M+Na]^+$; found: 1171.3279.

*5-(Methoxycarbonyl)pentyl (2,4-di-O-acetyl-6-O-tert-butylphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-trichloroacetamido-4,6-O-benzylidene-2-deoxy-β-D-glucopyranoside (**25**)*

A suspension of thiogalactoside **12** (170 mg, 0.24 mmol), acceptor **21** (100 mg, 0.19 mmol), and 3 Å molecular sieves (300 mg, freshly dried prior to use) in anhydrous CH_2Cl_2 (2 mL) was stirred at RT for 30 min under a nitrogen atmosphere, cooled to 0 °C, and sequentially treated with NIS (108 mg, 0.48 mmol) and TfOH (1.7 μL, 19 μmol). The reaction mixture was stirred at 0 °C for 30 min, quenched by the addition of Et_3N, and filtered through a pad of Celite. The filtrate was sequentially washed with a saturated aqueous solution of $NaHCO_3$, a saturated aqueous solution of $Na_2S_2O_3$, water, and brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to give compound **25** (142 mg, 77 % yield) as a yellowish amorphous foam. R_f = 0.28 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25} = -20$ (c = 1.3, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$,): δ = 7.56–7.53 (m, 4H; ArH), 7.53–7.34 (m, 8H; ArH), 7.19 (t, J = 7.4 Hz, 1H; ArH), 7.07 (t, J = 7.64 Hz, 2H; ArH), 7.02 (d, J = 7.4 Hz, 1H; NH), 5.51 (d, J = 3.24 Hz, 1H; H4′), 5.44 (s, 1H; PhCH), 5.16 (dd, J = 10.4, 7.9 Hz,

1H; H2′), 4.97 (d, J=8.5 Hz, 1H; H1), 4.94 (dd, J=10.4, 3.2 Hz, 1H; H3′), 4.68 (d, J=8.0 Hz, 4H; H1), 4.53 (t, J=9.4 Hz, 1H; H3), 4.30 (dd, J=10.5, 4.9 Hz, 1H; H6a), 3.86 (dt, J=9.6, 6.2 Hz, 1H; alkyl chain), 3.74 (t, J=10.3 Hz, 1H; H6b), 3.66 (s, 3H; CO_2CH_3), 3.65–3.63 (m, 2H; H6′ab), 3,60 (t, J=9.5 Hz, 2H; H4, H5′), 3.48 (dt, J=9.7, 6.2 Hz, 2H; H5, alkyl chain), 3.39 (dt, J=9.8, 9.7 Hz, 1H; H2), 2.78–2.73 (m, 1H; Lev-CH_2), 2.64–2.49 (m, 2H; Lev-CH_2), 2.41–2.34 (m, 1H; Lev-CH_2), 2.29 (t, J=7.6 Hz, 2H; CH_2CO_2Me), 2.18 (s, 3H; $COCH_3$), 2.04 (s, 3H; $COCH_3$), 1.92 (s, 3H; $COCH_3$), 1.66–1.52 (m, 4H; alkyl chain), 1.43–1.1.30 (m, 2H; alkyl chain), 0.99 ppm (s, 9H; tBu); ^{13}C NMR (100 MHz, $CDCl_3$): δ=207.2, 206.4, 174.35, 171.9, 170.3, 169.9, 162.1, 137.1, 135.9, 135.8, 132.9, 132.7, 130.1, 129.2, 128.2, 128.0, 127.9, 126.1, 101.1, 100.3, 99.5, 92.6, 79.6, 76.0, 73.0, 71.9, 70.4, 69.4, 68.7, 66.9, 66.4, 60.6, 59.6, 51.7, 37.8, 34.0, 31.1, 29.9, 29.2, 28.0, 26.9, 25.7, 24.8, 21.1, 20.8, 19.1 ppm; HRMS (ESI-TOF): m/z calcd for $C_{53}H_{66}Cl_3NO_{17}SiNa$: 1146.3045 $[M+Na]^+$; found: 1146.3024.

*Acetyl (2,4-Di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→4)-2-azido-3,6-di-O-benzyl-2-deoxy-β-D-glucopyranoside (**26**)*

The following glycosylation reaction was performed immediately after the sequential preparation of compound **12** without purification.

A solution of crude thiogalactoside **12** (which was obtained from a 4-step, consecutive procedure without purification; for details, see Scheme 2; 500 mg, 0.95 mmol of compound **10** were used at the start of the synthesis), acceptor **22** (487 mg, 1.14 mmol), and freshly activated 3 Å molecular sieves (2.0 g) in CH_2Cl_2 (10 mL) was stirred at RT for 30 min and then cooled to −45 °C under a nitrogen atmosphere. NIS (426 mg, 1.90 mmol) and TfOH (8.9 μL, 0.10 mmol) were sequentially added to the reaction and the resulting mixture was stirred at −45 °C for a further 1 h. The reaction was quenched by the addition of Et_3N, diluted with EtOAc, and filtered through a pad of Celite. The filtrate was washed with a saturated aqueous solution of $Na_2S_2O_3$, a saturated aqueous solution of $NaHCO_3$, water, and brine, dried over anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure. The resulting residue was purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to give compound **24** (520 mg, 54% overall yield for 5 steps starting from compound **10**) as a pale-yellow amorphous foam.

Preactivation method: A solution of purified thiogalactoside **12** (200 mg, 0.28 mmol), TTBP (73.0 mg, 0.29 mmol), and Ph_2SO (62 mg, 0.31 mmol) in anhydrous CH_2Cl_2/toluene (2:1, 6 mL) was stirred in the presence of 3 Å molecular sieves (400 mg, freshly dried prior to use) at RT for 30 min, cooled to −60 °C under a nitrogen atmosphere, and treated with Tf_2O (51 μL, 0.31 mmol). Upon consumption of the glycosyl donor (by TLC), a solution of glycosyl acceptor **22** (180 mg, 0.42 mmol) in anhydrous CH_2Cl_2 (6 mL) was added to the reaction and the resulting mixture was stirred at −60 °C for a further 1 h. The reaction was stopped by the addition of Et_3N and filtered through a pad of Celite. The filtrate was concentrated in vacuo and purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to afford compound **26** (234 mg, 80% yield) as a white amorphous foam.

The NIS/TfOH method: A suspension of purified thiogalactoside **12** (744 mg, 1.05 mmol), acceptor **22** (300 mg, 0.70 mmol), and freshly dried 3 Å molecular sieves (2.0 g) in anhydrous CH_2Cl_2 (7 mL) was stirred at RT for 30 min and then cooled to −45 °C under a nitrogen atmosphere. NIS (471 mg, 2.10 mmol) and TfOH (9.8 μL, 0.11 mmol) were added to the reaction and the mixture was stirred at the same temperature for a further 1 h. The reaction was stopped by the addition of Et_3N and filtered through a pad of Celite. The filtrate was sequentially washed with a saturated aqueous solution of $NaHCO_3$, a saturated aqueous solution of $Na_2S_2O_3$, water, and brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 2:3) to give compound **26** (596 mg, 84% yield) as a pale-yellow amorphous foam. R_f=0.30 (EtOAc/hexanes, 2:3 v/v); $[\alpha]_D^{25}=-44$ (c=1.1, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ=7.56–7.53 (m, 4H; ArH), 7.48–7.42 (m, 2H; ArH), 7.40–7.30 (m, 11H; ArH), 7.11–7.08 (m, 1H; ArH), 7.03–7.00 (m, 2H; ArH), 5.50 (d, J=3.3 Hz, 1H; H4′), 5.34 (d, J=8.5 Hz, 1H; H1), 5.06 (dd, J=8.1, 10.5 Hz, 1H; H2′), 4.93 (d, J=10.1 Hz, 1H; $PhCH_2$), 4.82 (dd, J=3.5, 10.5 Hz, 1H; H3′), 4.76 (d, J=12.0 Hz, 1H; $PhCH_2$), 4.59 (d, J=10.0 Hz, 1H; $PhCH_2$), 4.43 (d, J=8.0 Hz, 1H; H1′), 4.38 (d, J=12.0 Hz, 1H; $PhCH_2$), 4.02 (t, J=9.5 Hz, 1H; H5), 3.75 (dd, J=2.6, 11.2 Hz, 1H; H6a′), 3.69 (dd, J=1.3, 11.0 Hz, 1H; H6b′), 3.59 (dd, J=5.3, 9.6 Hz, 1H; H3), 3.48–3.44 (m, 2H; H2, H6a), 3.41–3.36 (m, 3H; H4, H5′, H6b), 2.84–2.78 (m, 1H; Lev-CH_2), 2.66–2.59 (m, 1H; Lev-CH_2), 2.57–2.51 (m, 1H; Lev-CH_2), 2.42–2.36 (m, 1H; Lev-CH_2), 2.18 (s, 3H; $COCH_3$), 2.15 (s, 3H; $COCH_3$), 2.02 (s, 3H; $COCH_3$), 1.98 (s, 3H; $COCH_3$), 1.02 ppm (s, 9H; tBu); ^{13}C NMR (125 MHz, $CDCl_3$): δ=206.2, 171.5, 170.0, 169.4, 169.1, 137.7, 137.4, 135.7, 135.5, 132.8, 129.9, 126.7, 128.4, 128.3, 128.2, 127.9, 127.8, 127.6, 99.8, 92.7, 81.1, 75.6, 75.5, 75.0, 73.7, 73.0, 71.5, 69.5, 67.0, 66.8, 64.2, 60.2, 37.7, 29.6, 27.8, 26.7, 21.0, 20.8, 20.6, 19.0 ppm; HRMS (ESI-TOF): m/z calcd for $C_{53}H_{63}N_3O_{15}SiNa$: 1032.3921 $[M+Na]^+$; found: 1032.3969.

*5-(Methoxycarbonyl)pentyl (2,4-di-O-acetyl-6-O-tert-butylphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→4)-2-trichloroacetamido-3,6-O-benzyl-2-deoxy-β-D-glucopyranoside (**27**)*

A suspension of thiogalactoside **12** (170 mg, 0.24 mmol), acceptor **23** (75.0 mg, 0.12 mmol), and 3 Å molecular sieves (300 mg, freshly dried prior to use) in anhydrous CH_2Cl_2 (2 mL) was stirred at RT for 30 min under a nitrogen atmosphere, cooled to 0 °C, and sequentially treated with NIS (69.0 mg, 0.31 mmol) and TfOH (1.6 μL, 19 μmol). The reaction was stirred at 0 °C for 30 min, stopped by the addition of Et_3N, and filtered through a pad of Celite. The filtrate was sequentially washed with a saturated aqueous solution of $NaHCO_3$, a saturated aqueous solution of $Na_2S_2O_3$, water, and brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to give compound **27** (90 mg, 76% yield) as a yellowish amorphous foam. R_f=0.45 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25}=-12$ (c=1.1, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$,): δ=7.57–7.54 (m, 4H; ArH), 7.48–7.27 (m, 11H; ArH), 7.27–7.20 (m, 2H; ArH), 7.17–7.08 (m, 1H; ArH), 7.03 (d, J=7.5 Hz, 1H; NH), 7.02–6.98 (m, 2H; ArH), 5.52 (d, J=3.45 Hz, 1H; H4′), 5.09 (dd, J=10.4, 7.9 Hz, 1H; H2′), 4.91 (dd, J=10.43, 3.45 Hz, 1H; H3′), 4.86 (d, J=7.53 Hz, 1H; H1), 4.83 (d, J=10.3 Hz, 1H; $PhCH_2$), 4.93 (d, J=12.1 Hz, 1H; $PhCH_2$), 4.50 (d, J=7.9 Hz, 1H; H1′), 4.48 (d, J=9.5 Hz, 1H; $PhCH_2$), 4.47 (d, J=12.7 Hz, 1H; $PhCH_2$), 4.30 (t, J=8.4 Hz, 1H; H3), 3.95 (t, J=8.0 Hz, 1H; H4), 3.74 (dt, J=9.7, 6.1 Hz, 1H; alkyl chain), 3.77–3.75 (m, 2H; H6ab), 3.66 (s, 3H; CO_2CH_3), 3,60 (dd, J=7.6, 3.5 Hz, 1H; H6′a), 3.52–3.47 (m, 5H; H2, H5, H5′, H6′b, alkyl chain), 2.80–2.78 (m, 1H; Lev-CH_2), 2.67–2.52 (m, 2H; Lev-CH_2), 2.43–2.41 (m, 1H; Lev-CH_2), 2.30 (t, J=7.5 Hz, 1H; CH_2CO_2Me), 2.19 (s, 3H; $COCH_3$), 2.06 (s, 3H; $COCH_3$), 1.98 (s, 3H; $COCH_3$), 1.56–1.53 (m, 4H; alkyl chain), 1.41–1.31 (m, 2H; alkyl chain), 1.02 ppm (s, 9H; tBu); ^{13}C NMR (100 MHz, $CDCl_3$): δ=174.3, 171.8, 170.19, 169.7, 161.8, 138.1, 138.0, 135.9, 135.7, 133.0, 130.1, 128.8, 128.3, 128.2, 128.0, 127.8, 100.4, 99.4, 92.7, 76.4, 75.3, 74.8, 73.8, 73.2, 71.6, 69.8, 69.7, 68.2, 67.0, 60.5, 57.7, 51.7, 37.9, 34.1, 29.9, 29.3, 28.0, 27.0, 25.8, 24.8, 21.0, 20.9, 19.2 ppm; HRMS (ESI-TOF): m/z calcd for $C_{60}H_{74}Cl_3NO_{17}SiNa$: 1238.3674 $[M+Na]^+$; found: 1238.3715.

*(2,4-Di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→4)-2-trichloroacetamido-3,6-di-O-benzyl-2-deoxy-αβ-D-glucopyranosyl N-phenyltirfluoroacetimidate (**29**)*

A solution of compound **26** (300 mg, 0.30 mmol) in anhydrous CH_2Cl_2/MeOH (1:1, 3 mL) was treated with a fresh 1.0 M solution of PEt_3 (0.36 mL, 0.36 mmol in THF) at 0 °C under a nitrogen atmosphere. After the addition had been completed, the ice bath was removed and the mixture was gradually warmed to RT, accompanied by the release of gas. The reaction was stirred at RT for a further 1 h and then concentrated in vacuo. The residue was kept under high vacuum for at least 2 h to remove most of the phosphine and redissolved in anhydrous CH_2Cl_2 (3 mL) at 0 °C under a nitrogen atmosphere. To the resulting solution were sequentially added trichloroacetic chloride (0.15 mL, 1.35 mmol) and Et_3N (0.25 mL, 1.80 mmol). The mixture was stirred at 0 °C for 15 min and then poured into ice water for extraction. The combined organic layers were washed with a saturated aqueous solution of $NaHCO_3$ and brine, dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified by column chromatography on silica gel (EtOAc/

hexanes, 3:2) to give the trichloroacetamide-protected product **28** (171 mg, 53% overall yield in 3 steps) as a white amorphous foam.

A solution of compound **28** (150 mg, 0.14 mmol) in anhydrous CH_2Cl_2 (3 mL) was treated with Cs_2CO_3 (91 mg, 0.28 mmol) and 2,2,2-trifluoro-*N*-phenylacetimidoyl chloride (87 mg, 0.42 mmol) at 0°C under a nitrogen atmosphere, gradually warmed to RT, and stirred for 16 h. The resulting mixture was filtered through a pad of Celite. The filtrate was concentrated in vacuo and purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to afford compound **29** (110 mg, 63% yield) as a white amorphous foam (α,β-mixture, α/β 1.8:1). R_f = 0.65 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25}$ = +26 (c = 1.2, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.56–7.52 (m, 11.2H; ArH(α+β)), 7.46–7.30 (m, 30.8H; ArH(α+β)), 7.28–7.25 (m, 5.6H; ArH(α+β)), 7.22–7.08 (m, 16.8H; ArH+NH(α+β)), 6.76 (d, J = 7.7 Hz, 3.6H; ArH(α)), 6.50 (d, J = 7.6 Hz, 2H; ArH(β)), 6.45 (br, 1.8H; H1(α)), 6.27 (d, J = 7.4 Hz, 1H; H1(β)), 5.52 (d, J = 3.4 Hz, 1H; H4′(β)), 5.52 (d, J = 3.5 Hz, 1.8H; H4' (α)), 5.10 (dd, J = 10.4, 8.3 Hz, 1.8H; H2′(α)), 5.07 (dd, J = 10.4, 7.8 Hz, 1H; H3′(β)), 4.91 (dd, J = 10.4, 3.5 Hz, 1H; H3′(β)), 4.87 (dd, J = 10.4, 3.5 Hz, 1.8H; H3′(α)), 4.89 (ABq, J = 10.9 Hz, 1.8H; $PhCH_2$(α)), 4.75 (ABq, J = 12.0 Hz, 1.8H; $PhCH_2$(α)), 4.66 (ABq, J = 12.4 Hz, 1H; $PhCH_2$(β)), 4.56 (ABq, J = 10.9 Hz, 1.8H; $PhCH_2$(α)), 4.56 (ABq, J = 10.8 Hz, 1H; $PhCH_2$(β)), 4.49 (ABq, J = 12.4 Hz, 1H; $PhCH_2$(β)), 4.49 (ABq, J = 10.8 Hz, 1H; $PhCH_2$(β)), 4.47 (d, J = 8.5 Hz, 1.8H; H-1(α)), 4.45 (ABq, J = 12.0 Hz, 1.8H; $PhCH_2$(α)), 4.38 (d, J = 8.0 Hz, 1H , H-1′(β)), 4.37 (td, J = 7.4, 1.0 Hz, 1H; H2(β)), 4.19 (t, J = 2.3 Hz, 1H; H6a(β)), 4.15–4.11 (m, 1.8H; H2(α)), 4.12 (t, J = 7.2 Hz, 1H; H4(β)), 4.10 (t, J = 9.3 Hz, 1.8H; H4(α)), 3.98–3.94 (m, 1H; H5(β)), 3.79–3.71 (m, 5.6H (α+β)), 3.67–3.41 (m, 9.2H (α+β)), 2.86–2.75 (m, 2.8H (α+β); Lev-CH_2), 2.66–2.50 (m, 5.6H; Lev-CH_2), 2.42–2.36 (m, 2.8H; Lev-CH_2), 2.17 (s, 5.6H; $COCH_3$(α+β)), 2.16 (s, 3H; $COCH_3$(β)), 2.06 (s, 5.6H; $COCH_3$(α)), 2.02 (s, 3H; $COCH_3$(β)), 1.97 (s, 5.6H; $COCH_3$(α)), 1.93 (s, 3H; $COCH_3$(β)), 1.01 ppm (s, 25.2H; *t*Bu(α+β)); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 206.44, 206.41, 171.84, 171.79, 170.3, 170.2, 169.7, 169.2, 162.9, 162.0, 143.2, 137.98, 137.92, 137.8, 137.6, 135.86, 135.82, 135.76, 135.70, 133.03, 133.0, 132.8, 130.2, 130.13, 130.1, 130.08, 128.99, 128.96, 128.8, 128.62, 128.61, 128.5, 128.49, 128.3, 128.2, 128.17, 128.05, 128.00, 127.98, 127.5, 119.6, 104.3, 102.3, 100.4, 92.3, 86.5, 77.6, 76.2, 75.7, 74.9, 74.0, 73.73, 73.71, 73.3, 73.2, 72.1, 71.7, 71.6, 71.1, 69.7, 69.1, 68.8, 67.1, 67.05, 66.9, 66.3, 60.8, 60.6, 54.0, 37.9, 37.89, 29.88, 29.86, 28.07, 28.02, 27.0, 26.9, 21.1, 20.9, 20.84, 20.81, 19.23, 19.19 ppm; HRMS (ESI-TOF): m/z calcd for $C_{61}H_{65}Cl_3F_3N_2O_{15}Si$: 1255.3166 $[M-H]^+$; found: 1255.3258.

*5-(Methoxycarbonyl)pentyl (2,4-di-O-acetyl-6-O-tert-butyldiphenylsilyl-β-D-galactopyranosyl)-(1→4)-2-trichloroacetamido-3,6-di-O-benzyl-2-deoxy-β-D-glucopyranoside (**30**)*

A suspension of glycosyl donor **29** (150 mg, 0.12 mmol), methyl 6-hydroxyhexanoate (26 mg, 0.18 mmol), and 3 Å molecular sieves (350 mg, freshly dried prior to use) in anhydrous CH_2Cl_2 (2 mL) was stirred at RT for 30 min, cooled to 0°C under a nitrogen atmosphere, and treated with a catalytic amount of TMSOTf (6.5 μL, 36.0 μmol). The reaction was stirred at 0°C for 1 h, quenched by the addition of Et_3N, and filtered through a pad of Celite. The filtrate was washed with a saturated aqueous solution of $NaHCO_3$ and brine and dried over anhydrous $MgSO_4$. The filtrate was evaporated in vacuo, redissolved in anhydrous THF/MeOH (9:1, 2 mL), and treated with hydrazine monoacetate (22 mg, 0.24 mmol) at 0°C under a nitrogen atmosphere. Then, the ice bath was removed and the mixture was stirred at RT for a further 2 h. The solution was extracted with EtOAc and the combined organic layer was washed with a saturated aqueous solution of $NaHCO_3$, water, and brine, dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified by column chromatography on silica gel (EtOAc/hexanes, 1:1) to give compound **30** (95.9 mg, 72% in two steps) as a white amorphous foam. R_f = 0.28 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25}$ = −20 (c = 1.1, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.57–7.56 (m, 4H; ArH), 7.47–7.42 (m, 2H; ArH), 7.39–7.36 (m, 4H; ArH), 7.34–7.29 (m, 5H; ArH), 7.22–7.20 (m, 2H; ArH), 7.09–7.06 (m, 1H; ArH), 7.03 (d, J = 7.2 Hz, 1H; NH), 7.03–6.99 (m, 2H; ArH), 5.47 (d, J = 3.3 Hz, 1H; H4′), 4.87 (dd, J = 10.1, 7.8 Hz, 1H; H2′), 4.85 (d, J = 7.50 Hz, 1H; H1), 4.81 (ABq, J = 10.4 Hz, 1H; $PhCH_2$), 4.71 (ABq, J = 11.9 Hz, 1H; $PhCH_2$), 4.48 (ABq, J = 10.4 Hz, 1H; $PhCH_2$), 4.47 (d, J = 7.8 Hz, 1H; H1′), 4.47 (ABq, J = 11.9 Hz, 1H; $PhCH_2$), 3.99 (t, J = 8.3 Hz, 1H; H3), 3.95 (t, J = 7.8 Hz, 1H; H4), 3.84 (dt, J = 9.9, 6.2 Hz, 1H; OCH_2), 3.81–3.76 (m, 2H; H6a,b′), 3.68 (dt, J = 10.1, 4.2 Hz, 1H; H3′), 3.65 (s, 3H; $COOCH_3$), 3.61 (dd, J = 9.6, 5.5 Hz, 1H; H6a), 3.55–3.42 (m, 5H; H5, H6b, OCH_2, H2, H5′), 2.41–2.39 (br, 1H; OH), 2.27 (t, J = 7.5 Hz, 2H; CH_2COOCH_3), 2.08 (s, 3H; $COCH_3$), 2.01 (s, 3H; $COCH_3$), 1.64–1.53 (m, 6H; alkyl chain), 1.38–1.32 (m, 2H; alkyl chain), 1.03 ppm (s, 9H; *t*Bu); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 174.3, 171.5, 170.8, 161.9, 138.2, 135.9, 135.7, 133.1, 133.0, 130.12, 130.08, 128.7, 128.3, 128.2, 128.0, 127.8, 100.3, 99.5, 92.7, 76.5, 75.4, 74.6, 73.8, 73.5, 73.4, 72.0, 69.8, 69.7, 68.4, 60.8, 57.5, 51.7, 34.1, 29.3, 27.0, 25.8, 24.9, 21.2, 21.0, 19.3 ppm; HRMS (ESI-TOF): m/z calcd for $C_{55}H_{68}Cl_3NO_{15}SiNa$: 1138.3316 $[M+Na]^+$; found: 1138.3366.

*5-(Methoxycarbonyl)pentyl (2,4-di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→4)-(2-trichloroacetamido-3,6-di-O-benzyl-2-deoxy-β-D-glucopyranosyl)-(1→3)-(2,4-di-O-acetyl-6-O-tert-butyldiphenylsilyl-β-D-galactopyranosyl)-(1→4)-2-trichloroacetamido-3,6-di-O-benzyl-2-deoxy-β-D-glucopyranoside (**31**)*

A suspension of glycosyl donor **29** (100 mg, 79.5 μmol), glycosyl acceptor **27** (59 mg, 53.0 μmol), and 3 Å molecular sieves (320 mg, freshly dried prior to use) in anhydrous CH_2Cl_2 (1 mL) was stirred at RT for 30 min under a nitrogen atmosphere, cooled to 0°C, and a catalytic amount of TMSOTf (2.9 μL, 15.9 μmol) was added. The reaction was stirred at 0°C for a further 1 h, quenched by the addition of Et_3N, and filtered through a pad of Celite. The filtrate was concentrated under reduced pressure and purified by column chromatography on silica gel (EtOAc/hexanes, 1:2) to give compound **31** (64.3 mg, 62% yield) as a white amorphous foam. R_f = 0.42 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25}$ = −4.4 (c = 0.7, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.59 (d, J = 7.6 Hz, 4H; ArH), 7.55–7.52 (m, 4H; ArH), 7.46–7.27 (m, 22H; ArH), 7.21 (d, J = 8.9 Hz, 2H; ArH), 7.16 (d, J = 7.1 Hz, 2H; ArH), 7.09–7.01 (m, 5H; ArH, NH), 6.98–6.95 (m, 3H; ArH, NH), 5.514 (d, J = 3.6 Hz, 1H; H4‴), 5.508 (d, J = 3.6 Hz, 1H; H4′), 5.06 (dd, J = 10.4, 7.7 Hz, 1H; H2‴), 5.06 (dd, J = 10.4, 8.3 Hz, 1H; H2′ overlapped with H2‴ and H1″), 5.03 (d, J = 8.3 Hz, 1H; H1″), 4.95 (dd, J = 10.4, 3.6 Hz, 1H; H3‴), 4.80 (ABq, J = 10.4 Hz, 1H; $PhCH_2$), 4.76 (d, J = 7.2 Hz, 1H; H1), 4.72 (ABq, J = 10.9 Hz, 1H; $PhCH_2$), 4.70 (ABq, J = 11.7 Hz, 1H; $PhCH_2$), 4.65 (ABq, J = 11.7 Hz, 1H; $PhCH_2$), 4.54 (d, J = 7.7 Hz, 1H; H1‴), 4.52 (ABq, J = 10.9 Hz, 1H; $PhCH_2$), 4.49 (ABq, J = 11.7 Hz, 1H; $PhCH_2$), 4.46 (ABq, J = 11.7 Hz, 1H; $PhCH_2$), 4.44 (ABq, J = 10.4 Hz, 1H; $PhCH_2$), 4.35 (d, J = 8.3 Hz, 1H; H1′), 3.98–3.92 (m, 3H; H4, H3″, H4″), 3.89 (t, J = 7.2 Hz, 1H; H3), 3.85–3.74 (m, 5H; H6a′, alkyl chain, H6a,b, H3′), 3.71 (dd, J = 10.4, 4.0 Hz, 1H; H6b′), 3.64 (s, 3H; $COOCH_3$), 3.62–3.59 (m, 1H; H2), 3.60–3.37 (m, 9H; H5, H5′, H5″, H5‴, H6a,b, H6a,b″, alkyl chain), 3.36–3.32 (m, 1H; H2″), 2.81 (ddd, J = 18.2, 6.1, 5.3 Hz, 1H; Lev-CH_2), 2.65–2.52 (m, 2H; Lev-CH_2), 2.39 (dt, J = 17.3, 6.1 Hz, 1H; Lev-CH_2), 2.26 (t, J = 7.5 Hz, 2H; CH_2COOCH_3), 2.17 (s, 3H; CH_2COCH_3), 2.06 (s, 3H; $COCH_3$), 2.05 (s, 3H; $COCH_3$), 2.03 (s, 3H; $COCH_3$), 1.93 (s, 3H; $COCH_3$), 1.88 (s, 3H; $COCH_3$), 1.63–1.54 (m, 6H; alkyl chain), 1.39–1.32 (m, 2H; alkyl chain), 1.01 (s, 9H; *t*Bu), 1.00 ppm (s, 9H; *t*Bu); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 206.5, 174.3, 171.8, 170.2, 169.8, 169.6, 169.5, 161.85, 161.81, 138.2, 138.12, 138.08, 135.9, 135.7, 133.2, 132.96, 132.94, 130.1, 130.03, 130.01, 128.7, 128.3, 128.25, 128.21, 128.13, 128.09, 128.04, 128.0, 127.97, 127.93, 127.7, 100.6, 100.5, 99.6, 98.8, 92.7, 92.6, 77.3, 76.5, 76.3, 75.7, 75.66, 75.4, 74.33, 74.29, 74.0, 73.8, 73.78, 73.3, 71.8, 71.6, 69.7, 69.0, 68.7, 68.6, 67.0, 61.5, 60.4, 57.6, 56.4, 51.7, 37.9, 34.1, 29.9, 29.3, 28.0, 27.0, 26.96, 25.8, 24.9, 21.4, 21.0, 20.9, 20.8, 19.3, 19.2 ppm; HRMS (MALDI-TOF): m/z calcd for $C_{108}H_{128}Cl_6N_2O_{29}Si_2Na$: 2209.6158 $[M+Na]^+$; found: 2209.6160.

*6-Azidohexyl (2,4,-di-O-acetyl-6-O-tert-butyldiphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-azido-4,6-O-benzylidene-2-deoxy-β-D-glucopyranoside (**33**)*

R_f = 0.40 (EtOAc/hexanes, 1:1 v/v); $[\alpha]_D^{25}$ = −16 (c = 1.6, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.53 (d, J = 6.9 Hz, 2H; ArH), 7.48 (d, J = 6.9 Hz, 2H; ArH), 7.45–7.40 (m, 2H; ArH), 7.37–7.32 (m, 6H; ArH), 7.24–7.14 (m, 3H; ArH), 5.69 (d, J = 6.9 Hz, 1H; NH), 5.50 (d, J = 3.4 Hz, 1H; H4′), 5.41 (s, 1H; PhCH), 5.16 (d, J = 8.5 Hz, 1H; H1), 5.14 (dd, J = 10.2,

7.9 Hz, 1H; H2′), 4.99 (dd, J=10.2, 3.4 Hz, 1H; H3′), 4.76 (d, J=7.9 Hz, 1H; H1′), 4.63 (dd, J=9.3, 4.2 Hz, 1H; H3), 4.28 (dd, J=10.3, 4.5 Hz, 1H; H6a), 3.82 (td, J=10, 7 Hz, 1H; OCH_2), 3.71–3.68 (m, 1H; H6b), 3.66 (t, J=4.2 Hz, H4), 3.64–3.56 (m, 3H; H5 and H6ab′), 3.51 (t, J=7 Hz, 1H; OCH_2), 3.50–3.47 (m, 1H; H5′), 3.26 (t, J=6.9 Hz, 2H; CH_2N_3), 2.99 (dd, J=9.3, 8.5 Hz, 1H; H2), 2.82–2.75 (m, 1H; Lev-CH_2), 2.63–2.50 (m, 2H; Lev-CH_2), 2.41–2.36 (m, 1H; Lev-CH_2), 2.16 (s, 3H; $COCH_3$), 2.09 (s, 3H; $COCH_3$), 2.00 (s, 3H; $COCH_3$), 1.90 (s, 3H; $COCH_3$), 1.60–1.57 (m, 4H; alkyl chain), 1.40–1.37 (m, 4H; alkyl chain), 0.98 ppm (s, 9H; tBu); ^{13}C NMR (125 MHz, $CDCl_3$): δ=206.3, 171.7, 170.6, 170.1, 169.7, 137.1, 135.8, 135.6, 132.8, 132.5, 129.9, 129.1, 128.6, 127.8, 127.7, 125.8, 101.0, 100.5, 99.3, 80.9, 77.3, 77.0, 76.8, 72.7, 71.7, 70.0, 69.8, 68.7, 66.7, 65.9, 60.5, 58.8, 37.7, 31.9, 29.7, 29.7, 28.8, 27.8, 26.7, 26.4, 25.5, 23.7, 22.7, 20.9 ppm; HRMS (ESI-TOF): m/z calcd for $C_{52}H_{68}N_4O_{15}Si$: 1017.1996 $[M+Na]^+$; found: 1017.1990.

*6-Azidohexyl (2,4-di-O-acetyl-6-O-tert-butylphenylsilyl-3-O-levulinoyl-β-D-galactopyranosyl)-(1→4)-2-acetamido-3,6-di-O-acetyl-2-deoxy-β-D-glucopyranoside (**34**)*

R_f=0.40 (EtOAc/hexanes, 2:1 v/v); $[\alpha]_D^{25}=-28$ (c=1.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ=7.62–7.56 (m, 4H; ArH), 7.46–7.36 (m, 6H; ArH), 5.64 (d, J=9.3 Hz, 1H), 5.54 (d, J=2.7 Hz, 1H), 5.09–4.96 (m, 3H), 4.48 (dd, J=12.1, 3.1 Hz, 1H), 4.43 (d, J=7.4 Hz, 1H), 4.37 (d, J=7.4 Hz, 1H), 4.09 (dd, J=5.1, 12.1 Hz, 1H), 4.01–3.96 (m, 1H), 3.84–3.76 (m, 1H; OCH_2), 3.74–3.65 (m, 3H), 3.60–3.55 (m, 2H), 3.18–3.37 (m, 1H; OCH_2), 3.25 (d, J=7.0 Hz, 2H), 2.82–2.76 (m, 1H; Lev-CH_2), 2.65–2.51 (m, 2H; Lev-CH_2), 2.42–2.37 (m, 1H; Lev-CH_2), 2.16 (s, 3H; $COCH_3$), 2.09 (s, 3H; $COCH_3$), 2.08 (s, 3H; $COCH_3$), 2.02 (s, 3H; $COCH_3$), 1.92 (s, 3H; $COCH_3$), 1.76 (s, 3H; $COCH_3$), 1.59–1.51 (m, 4H), 1.36–1.31 (m, 4H), 1.02 ppm (s, 9H; tBu); ^{13}C NMR (125 MHz, $CDCl_3$): δ=206.1, 171.6, 170.4, 170.3, 169.9, 169.7, 135.5, 135.4, 132.6, 132.5, 129.94, 129.93, 127.8, 127.76, 127.68, 100.9, 100.8, 75.6, 73.1, 72.5, 72.4, 71.3, 69.1, 66.5, 62.3, 60.6, 52.8, 51.3, 37.6, 29.6, 29.2, 28.7, 27.7, 26.6, 26.3, 25.4, 23.1, 20.8, 20.6, 20.56, 20.51, 18.9 ppm; HRMS (ESI-TOF): m/z calcd for $C_{49}H_{68}N_4O_{17}SiNa$: 1035.4241 $[M+Na]^+$; found: 1035.4244.

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